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TROTT COMPUTER PROGRAM FOR TWO-DIMENSIONAL STRESS WAVE PROPAGATION

Prepared by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

TROTT is a Lagrangian finite-difference computer program for calculating two-dimensional stress wave propagation through solid, porous, and composit materials The stress waves may be caused by impact, detonation of an explosive, or a prescribed velocity.

The calculational procedure is the standard leapfrog method of von Neumann and Richtmyer, using artificial viscosity to smooth shock fronts. Quadrilateral or triangular cells are used. The momentum relations are derived by treating

#20, continued.

the cells as finite elements. Axisymmetric or planar flow can be handled.

The constitutive relations include the standard Mie-Gruneisen equation-of-state and elastic-plastic, work-hardening deviator stress relations. A polytropic gas and detonating flow relations are provided for explosives. Ductile and brittle fracture and shear banding are provided by nucleation and growth models. Porous materials can be represented by a cap plasticity model. A model for layered composities is also present.

The code is constructed for easy insertion of additional material models. The number of extra variables required for each cell for a material model can be specified on an input card.

This manual includes many sample problems, a derivation of the flow equations, and a discussion of material models.

FOREWORD

This volume constitutes Volume III of the three-volume final report to Ballistics Research Laboratory on Contract DAAK11-77-C-0083, SRI Project 6802. Volume I reports on ballistic experiments and calculations, and describes work on the latest version of the SRI brittle fracture subroutine. Volume II is the manual for the one-dimensional wave propagation code SRI PUFF 8.

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1. INTRODUCTION

The TROTT code is a finite-difference computer program for treating two-dimensional stress wave propagation caused by impacts or explosive detonation in either planar or axisymmetric flow. Calculations are made with the Lagrangian form of the equations of motion so that the coordinates move with the materials. Artificial viscosity is used to spread wave fronts over several cells. This manual provides a preliminary description of the algebra of the code and exhibits input for several types of calculations.

The TROTT code was constructed largely as a means for exercising the special material models under construction at SRI. This emphasis is reflected in the special features of the code:

- The code can accommodate complicated material models with large amounts of storage per cell. The insertion procedure for new models and the provision for additional storage for cells are described in Appendices A and B.
- The code is simple and can be easily modified. Input decks are small (see the sample input decks in Appendix C).
- The cell layout is easy and permits flexibility in initializing velocity distributions.
- The code is core-contained.
- The TROTT cells are treated as finite elements for mass and momentum calculations.

Because of the code's simplicity, it runs about three times faster than standard two-dimensional codes. Two additional features are being added to improve the treatment of large deformation problems: elementary slide lines are available and an automatic rezoner has been written but is not in the current version of TROTT. Although the core-contained feature simplifies the code, it also restricts the size of problems that can be treated.

TROTT was derived independently, but it is similar to many other two-dimensional Lagrangian codes. Early codes of this type are HEMP (Ref. 1) and TOODY (Ref. 2). More recent developments are WAVEL (Ref. 3) and STEALTH (Ref. 4). These four are all large codes containing slide lines, rezoning, and buffering of cell variables, but they have difficulty in incorporating new material models with large numbers of variables per cell.

2. ORGANIZATION OF THE CODE

TROTT computes stress waves caused by impact or explosive detonation. The governing equations are numerically integrated by the leapfrog method of von Neumann and Richtmyer (Ref. 5). For the calculations, the material is divided into small cells or continuum elements. The computations proceed by stepping forward in time in small increments. At each increment, calculations are made of stress, velocity, displacement, and so on at each cell and coordinate point.

The primary routines of the program are TROTT (overall control), LAYOUTT (initialization), SWEEPT (propagation calculations for each cell), and SCRIBET (printing historical listings). The flow of program control is illustrated in Figure 1, which shows the relations between the subroutines and the main program. A brief description of the work of each subroutine follows:

- TROTT, the main program, sets the size of the variable storage, calls LAYOUTT for initialization, calls SWEEPT for propagation calculations, writes restart dumps and plot files, sets the time increments, and calls SCRIBET for historial listings.

- LAYOUTT zeroes arrays, reads input, lays out the cells, and initializes cell variables.

- SWEEPT performs a calculation for all cells at a time step at each call. It computes the coordinate velocities from momentum conservation, computes strains, and then either calculates stress or calls a material model subroutine to obtain the stress. This routine also stores variables for the historical listings.

- SCRIBET writes the historical listings at the end of a problem.

- REBAR computes stresses in a layered composite such as reinforced concrete (see Ref. 6).

- CAP1 provides stress and tensile fracture in a porous material with a combined Mohr-Coulomb yield and compaction behavior (see Ref. 6).

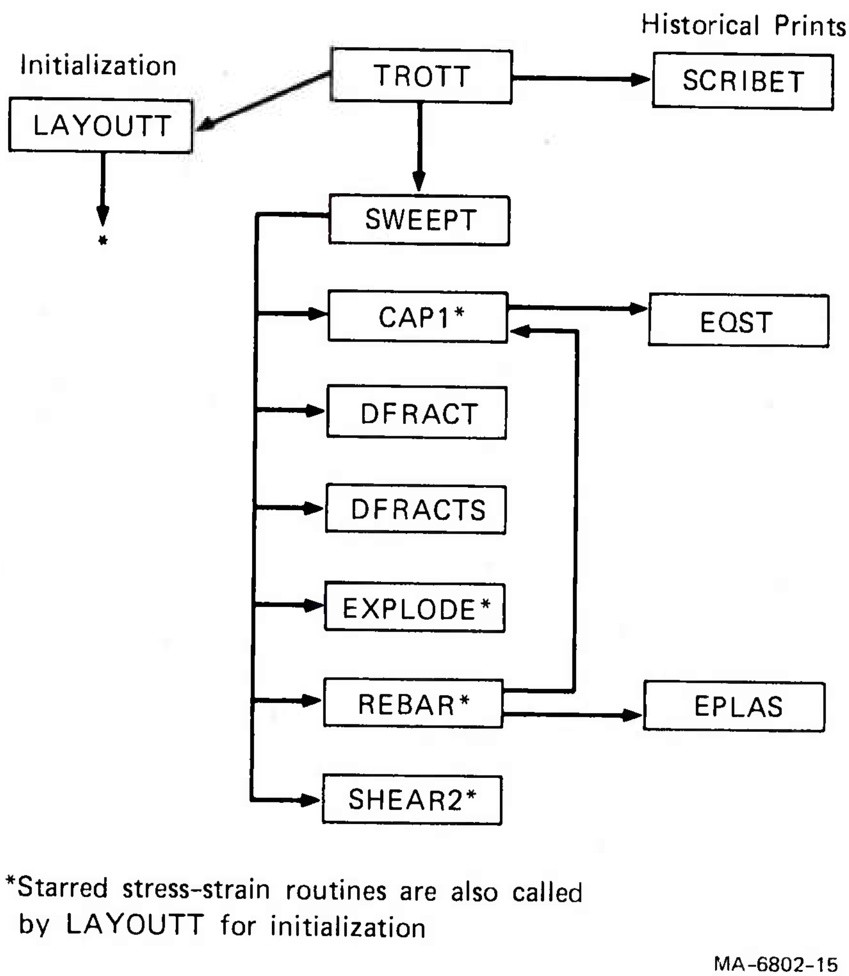


FIGURE 1 FLOW CHART OF TROTT

- EPLAS computes stress for a work-hardening elastic-plastic material (see Ref. 6).
- DFRACT computes stress and void growth in material undergoing ductile fracture (see Ref. 7).
- BFRACT provides stress and crack growth in material undergoing brittle fracture (see Refs. 7,8).
- SHEAR2 computes stress and damage for material undergoing shear banding (see Ref. 9).
- DFRACTS computes stress and void growth for static ductile fracture (see Ref. 10).
- EXPLODE provides pressure in explosives (described in Appendix D).

A listing of the program and all subroutines is provided in Appendix E. Appendix F is a glossary of the nomenclature used in the equations of this report and the nomenclature used for input quantities and other major variables in the computer program.

3. PROPAGATION CALCULATIONS: SWEEPT

The motion and stresses throughout the material are determined as a function of time in the code. The solution is effected by solving the mass, momentum, and energy conservation relations together with constitutive relations for the material as outlined in this section.

The material is first divided into discrete units or cells. Motions, energies, and other quantities are initialized in cells as required for the particular problem. Then the propagation calculations begin. As a guide in understanding the relationship of the conservation relations, constitutive relations, and the solution procedure, Figure 2 shows the cell quantities on a time-distance plot. For simplicity, Figure 2 contains only one independent spatial direction (Eulerian X or Lagrangian J). Coordinate quantities (location and velocity) are defined only at cell boundaries and at full or half-time increments. All other quantities (such as stress) are determined at cell midpoints and full time increments. The momentum calculation (or F = Ma) is used to determine velocity changes. For example, in Figure 2, the stresses $\sigma_{J,n}$ and $\sigma_{J+1,n}$ in adjacent cells at the n^{th} time step determine the forces on the mass centered at point (J,n). The acceleration of this mass determines the change in velocity $\dot{X}_{J,n-1/2}$ to $\dot{X}_{J,n+1/2}$. From the new velocity, the coordinate position $X_{J,n+1}$ is obtained. With the coordinate positions at time n+1 known, the strains and density are also obtainable. Next the stresses such as $\sigma_{J,n+1}$ are calculated from the strains and density, using the constitutive relations. The procedure is continued to the right through each cell for each time increment. This process of stepping forward in time and performing calculations for each cell is repeated until the time has reached the duration of interest. The time step is controlled by the stability and smoothness criteria described in this section. Following the motion calculations, the strain increments are computed.

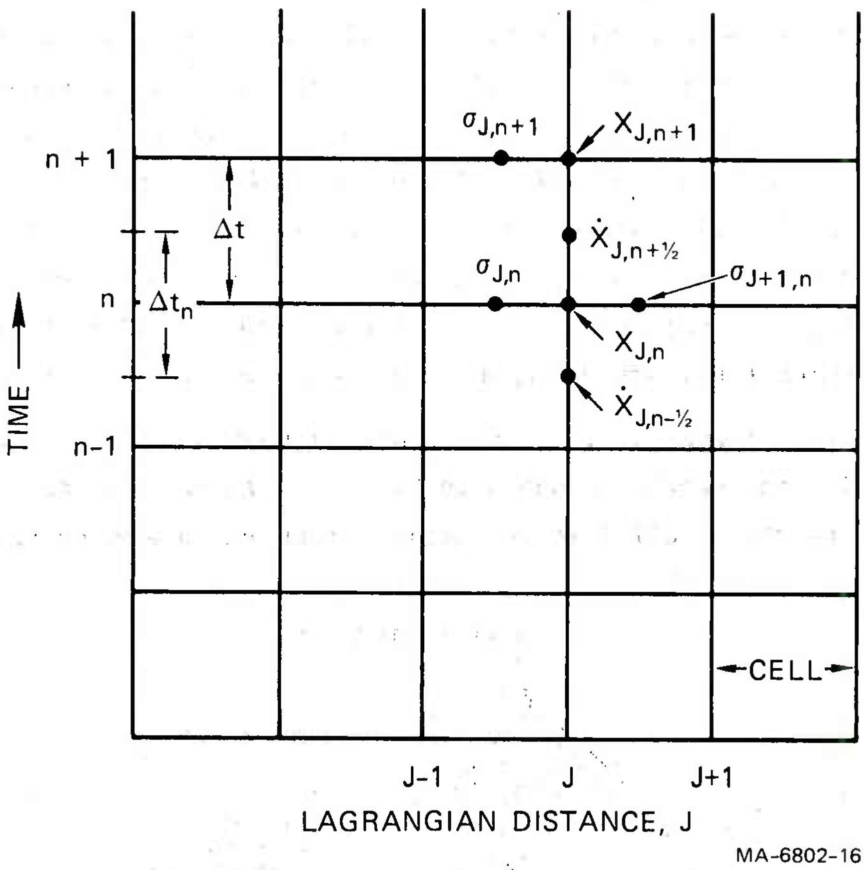


FIGURE 2 FINITE-DIFFERENCE GRID SHOWING LOCATIONS OF VARIABLES USED IN THE MOMENTUM CONSERVATION RELATIONS

3.1 Solution of Conservation Relations

The conservation relations for mass, momentum, and energy are the basic equations governing the wave propagation process. Mass conservation is effected in the code by using Lagrangian cells that maintain a constant mass throughout the problem. Momentum conservation relations are used to obtain the coordinate motions, and energy conservation is the basis of the internal energy calculation. First, momentum conservation is treated here, then the energy computation.

In deriving momentum conservation relations, it is possible to use a discretization of the differential equations of momentum conservation or to consider force balances around a finite element. The following derivation uses the second point of view, a finite element. Therefore, the steps in the calculation are to isolate a volume element for which the acceleration and velocity are computed, compute the forces acting on that element, and compute the mass of the element. Quadrilateral cells, the more common type, are treated first, and then triangular cells.

Two types of quadrilateral cells are defined for the wave propagation calculation. Both are shown in Figure 3, which contains a grid of coordinate points. Cell A is the natural cell surrounded by four

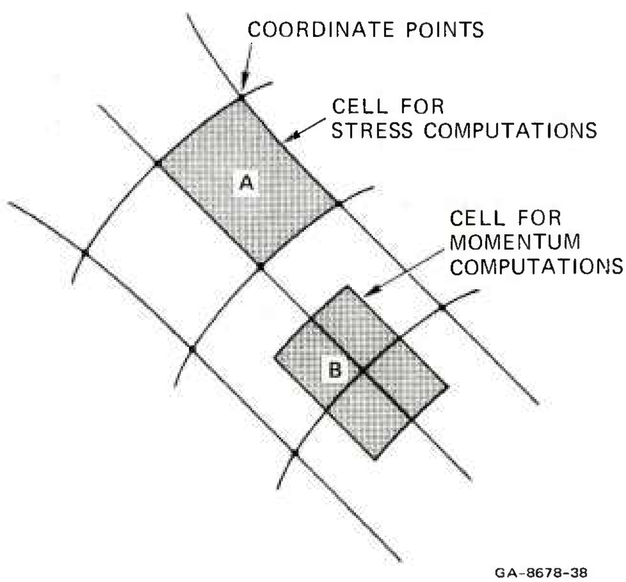


FIGURE 3 TYPES OF CELLS FOR STRESS AND MOMENTUM COMPUTATIONS

coordinate points. This is the cell for which the strains and stresses, which are homogeneous throughout each cell, are computed. The momentum computation determines the velocity of the coordinate points. For these calculations cell B, containing the mass around a coordinate point, is used. The calculations are broken into four portions corresponding to the parts lying in each of the surrounding stress cells. One typical portion is shown in Figure 4 with the nomenclature and sign conventions that are used in the derivation of momentum conservation or velocity change at point 3. (Stress is positive in tension.) Note that the standard axisymmetric shell is a ring or doughnut, whereas the planar cell is quadrilateral with indefinite thickness in the Z direction.

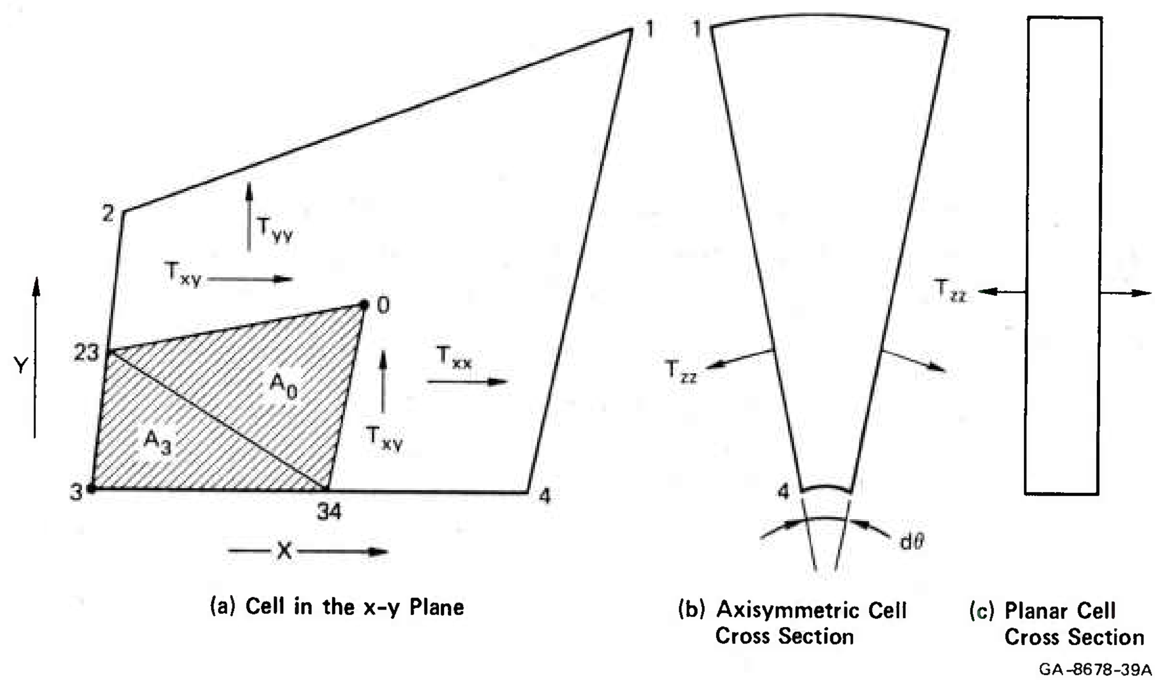


FIGURE 4 STRESS AND COORDINATE NOMENCLATURE FOR AXISYMMETRIC AND PLANAR CELLS

The configuration of the shaded element in Figure 4 is defined in such a way that the x and y coordinates of the point 0 are averages of

the coordinates at the four corners of the stress cell. End views are shown in Figure 4 as a reminder of the three-dimensional character of the elements. For an axisymmetric cell, the areas of the shaded element on which stresses act in the x and y directions are:

$$A_{xx} = \frac{d\theta}{4}(y_2 - y_4)\left(\frac{y_2 + y_4}{2} + y_3\right) \tag{1}$$

$$A_{yy} = \frac{d\theta}{2}\left[\left(\frac{y_2 + y_3}{2} + y_0\right)\left(x_0 - \frac{x_2 + x_3}{2}\right) - \left(\frac{y_3 + y_4}{2} + y_0\right)\left(x_0 - \frac{x_3 + x_4}{2}\right)\right] \tag{2}$$

For planar cells the areas in the x and y directions are:

$$A_{xx} = \frac{1}{2}(y_2 - y_4) \tag{3}$$

$$A_{yy} = \frac{1}{2}(x_4 - x_2) \tag{4}$$

For the axisymmetric case, the area in the x-y plane on which the stress acts is broken into two portions A_0 and A_3 as shown in Figure 4. These portions and the total are:

$$A_0 = \frac{1}{8}[(2x_0 - x_3)(y_2 - y_4) + x_2(y_3 + y_4 - 2y_0) + x_4(2y_0 - y_2 - y_3)] \tag{5}$$

$$A_3 = \frac{1}{8}[x_4(y_2 - y_3) + x_3(y_4 - y_2) + x_2(y_3 - y_4)] \tag{6}$$

$$A_{xy} = A_0 + A_3 \tag{7}$$

Equations (5) and (6) are derived by simplifying the usual general relations for the area of a triangle.

The forces in the x and y directions applied to the small mass represented by the shaded area in Figure 4 are determined by multiplying the

stresses shown in Figure 4 times the areas in Eqs. (1)-(4) and (7). The expressions for the forces are:

$$F_x = T_{xy}A_{yy} + T_{xx}A_{xx} \tag{8}$$

and

$$F_y = T_{yy}A_{yy} + T_{xy}A_{xx} - T_{zz}A_{xy}d\theta \quad \text{(axisymmetric)} \tag{9}$$

$$= T_{yy}A_{yy} + T_{xy}A_{xx} \quad \text{(planar)}$$

For the axisymmetric case, each force term contains the angle $d\theta$, which is left undefined. When force is divided by mass to obtain the velocity change, $d\theta$ is removed. The sign convention for the area computations is such that the product of stress and area is positive in the increasing x and y directions. Because each cell is written with point 3 as the one for which velocity is to be determined, the preceding forces and areas are valid for all quadrilateral cells around the point.

The mass of the small element is determined by multiplying the average density, ρ, of the cell shown in Figure 4 times the volume of the element. The axisymmetric cell mass is as follows:

$$M = \rho\frac{d\theta}{3}\left[A_0\left(y_0 + y_3 + \frac{y_2 + y_4}{2}\right) + A_3\left(\frac{y_2 + y_4}{2} + 2y_3\right)\right] \tag{10}$$

For the planar cells the mass is simply

$$M = \rho A_{xy} \tag{11}$$

Newton's second law is applied to obtain the change in velocity at the coordinate point 3, considering force and mass contributions from four quadrilateral elements around the point. (The index i runs over these elements.)

$$\Delta\dot{x} = \dot{x}_{n+1/2} - \dot{x}_{n-1/2} = \frac{\left(\sum_{i=1}^{4} F_{xi}\right)\Delta t_n}{\sum_{i=1}^{4} M_i} \tag{12}$$

where $\Delta\dot{x}$ is the change in velocity in the x direction over the time increment Δt_n. A similar relation is used for $\Delta\dot{y}$. The spatial and temporal relationships between the cell variables are shown in Figure 2.

Triangular cells are provided in TROTT by allowing the user to divide some quadrilateral cells into triangles with the orientation shown in Figure 5. The changes in the momentum equations to account for triangular cells are considered here. For the quadrilateral cells in the upper right and lower left corners of Figure 5, only one triangular cell is adjacent to the point 3. Therefore, the stresses, areas, and masses are derived entirely from that cell, and the previously derived equations are used. However, the coordinates of point 0 (Figure 4) are given by

$$x_o = 1/2(x_2 + x_4) \quad (13$$

$$y_o = 1/2(y_2 + y_4)$$

The mass and force contributions of the remaining four triangular cells in the upper left and lower right corners are determined separately and then summed. The area A_{xy} is computed as usual for a triangle:

$$A_{xy} = 1/8\left[x_4(y_1 - y_3) + x_3(y_4 - y_1) + x_1(y_3 - y_4)\right] \tag{14}$$

for a triangle with vertices at points 1, 3, and 4, and

$$A_{xy} = 1/8\left[x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2)\right] \tag{15}$$

for a triangle with vertices at 1, 2, and 3. For this same 1-2-3 triangle, the areas of axisymmetric cells in the x and y directions are

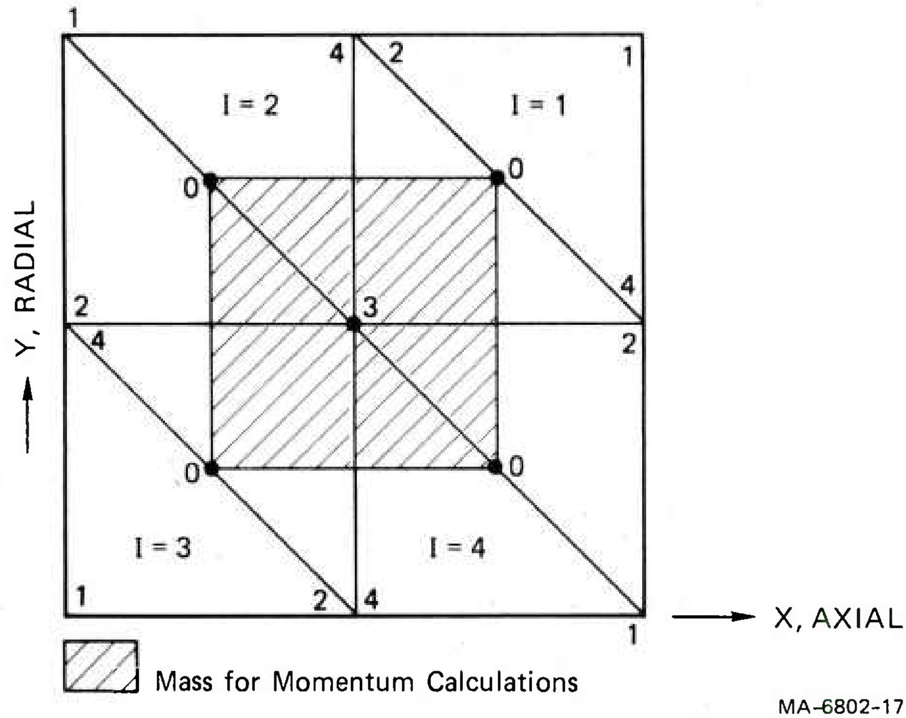


FIGURE 5 FOUR QUADRILATERAL CELLS DIVIDED INTO TRIANGULAR CELLS, PLUS THE MASS AT POINT 3 USED FOR MOMENTUM CALCULATIONS

$$A_{xx} = \frac{d\theta}{8}(y_2 - y_1)(y_2 + 2y_3 + y_1)$$

$$A_{yy} = \frac{d\theta}{8}(x_1 - x_2)(y_2 + 2y_3 + y_1) \tag{16}$$

For planar cells, the areas are

$$A_{xx} = 1/2(y_2 - y_1)$$

$$A_{yy} = 1/2(x_1 - x_2) \tag{17}$$

Areas for the 1-3-4 triangle are derived by a permutation of indices. Masses of the cells are obtained from an adaptation of Eq. (10) or (11).

Following calculation of the areas and masses of triangular cells, Eq. (12) is used to obtain the new velocity.

3.2 Strain Computation

The strain computations in the two-dimensional wave propagation program are based on the assumption that the strains are uniform throughout each quadrilateral cell of type A shown in Figure 3 and each triangular cell in Figure 5. The required strains are true strains. The strain computations are constructed to meet the following compatibility requirements:

$$\varepsilon_x + \varepsilon_y = \frac{\Delta A}{A} \tag{18}$$

$$\varepsilon_x + \varepsilon_y + \varepsilon_z = \frac{\Delta V}{V} \tag{19}$$

where

$\varepsilon_x, \varepsilon_y, \varepsilon_z$ = changes in the strain that occur during a time increment

ΔA = change in the cell area A in the x-y plane

ΔV = change in the volume V of the cell.

To ensure that compatibility of strains is enforced, we assume a velocity field (which is unique), rather than a strain field. Strains that are uniform throughout a cell are produced by the following linearly varying velocity field.

$$u = u_0 + u_x x + u_y y \tag{20}$$

$$v = v_0 + v_x x + v_y y \tag{21}$$

where u, v = particle velocity in the x, y directions, respectively.

The strain rates corresponding to these velocities are:

$$\dot{\varepsilon}_x = \frac{\partial u}{\partial x} = u_x \tag{22}$$

$$\dot{\varepsilon}_y = \frac{\partial v}{\partial y} = v_y \tag{23}$$

$$\dot{\varepsilon}_{xy} = \frac{1}{2}\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right) = \frac{1}{2}(v_x + u_y) \tag{24}$$

$$\dot{\omega}_{xy} = \frac{1}{2}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) = \frac{1}{2}(v_x - u_y) \tag{25}$$

where

$\dot{\varepsilon}_{xy}$ = tensor shear strain rate

$\dot{\omega}_{xy}$ = rotation rate in the xy plane.

The velocity fields of Eqs. (20) and (21) can be determined for any triangle if the velocities at the coordinate points are known. Consider for example the triangle in Figure 6 with coordinates 1, 2, and 3 and velocities in the x direction of u_1, u_2, and u_3. The velocity field parameters u_0, u_x, and u_y can then be determined from the following three equations:

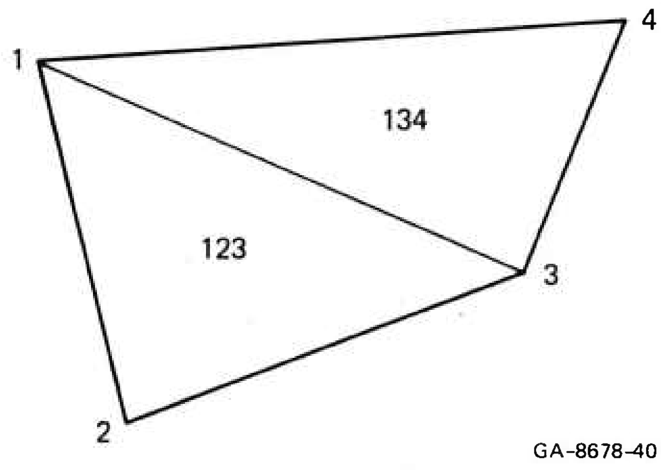


FIGURE 6 QUADRILATERAL ELEMENT PRODUCED FROM TWO TRIANGLES

$$u_1 = u_0 + u_x x_1 + u_y y_1$$

$$u_2 = u_0 + u_x x_2 + u_y y_2 \qquad (26)$$

$$u_3 = u_0 + u_x x_3 + u_y y_3$$

where the $x_i y_i$ are coordinates of the i^{th} point at some (as yet undetermined) time. Solution of Eqs. (26) gives the following results for u_x and u_y:

$$u_x = \frac{(u_1 - u_2)(y_1 - y_3) - (u_1 - u_3)(y_1 - y_2)}{2A} \qquad (27)$$

$$u_y = -\frac{(u_1 - u_2)(x_1 - x_3) - (u_1 - u_3)(x_1 - x_2)}{2A} \qquad (28)$$

where A, the area of the triangle 123 shown in Figure 6, is

$$\begin{aligned} 2A &= (x_1 - x_2)(y_1 - y_3) - (x_1 - x_3)(y_1 - y_2) \\ &= x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2) \end{aligned} \qquad (29)$$

Similarly the strain in the y direction can be determined.

$$v_x = \frac{(v_1 - v_2)(y_1 - y_3) - (v_1 - v_3)(y_1 - y_2)}{2A} \tag{30}$$

$$v_y = -\frac{(v_1 - v_2)(x_1 - x_3) - (v_1 - v_3)(x_1 - x_2)}{2A} \tag{31}$$

The next step is to specify x_i, y_i in Eqs. (27) through (31) in such a way that Eq. (18) is satisfied. This calculation is performed in two steps: first, the requirements are satisfied for each of the two triangles shown in Figure 6 and then the computation is made for the whole quadrilateral. To meet the requirement for triangle 123, the area A of Eq. (29) is taken as the average of the areas at the beginning and end of the time increment, that is,

$$A = \frac{1}{2}(A^0 + A^1) \tag{32}$$

A compatible form for the strain rate in the x direction is given by

$$\dot{\varepsilon}_x = \frac{A^0 u_x^0 + A^1 u_x^1}{A^0 + A^1} \tag{33}$$

where values with a superscript 0 are computed with initial values of x and y, and values with a superscript 1 are evaluated with final values of x and y. These final values of coordinates are

$$\begin{aligned} x_i^1 &= x_i^0 + u_i \Delta t \\ y_i^1 &= y_i^0 + v_i \Delta t \end{aligned} \tag{34}$$

Next we test the compatibility in Eq. (18) by substituting A from Eq. (32) (replacing the coordinates in A^1 with their values from Eq. 34), the strains from Eq. (33), and a comparable relation for ε_y, and letting $\Delta A = A^1 - A^0$. Then Eq. (18) is satisfied exactly, indicating that the expression for strain in Eq. (33) meets the first compatibility requirement.

For use in the computer program, Eq. (33) takes the form

$$\dot{\varepsilon}_x = \frac{u_{12}y_{13}^m - u_{13}y_{12}^m}{A^0 + A^1} \tag{35}$$

and

$$\dot{\varepsilon}_y = \frac{v_{13}x_{12}^m - v_{12}x_{13}^m}{A^0 + A^1} \tag{36}$$

for a 1-2-3 triangle, where the doubly subscripted velocities and coordinates have the following meaning

$$u_{ij} = u_i - u_j \tag{37}$$

$$x_{ij}^m = x_i - x_j + 1/2(u_i - u_j)\Delta t \tag{38}$$

The above result is extended to the full quadrilateral by using the following definition of the strain rate

$$\dot{\varepsilon}_x = \frac{A_1^0 u_{1x}^0 + A_1^1 u_{1x}^1 + A_2^0 u_{2x}^0 + A_2^1 u_{2x}^1}{A_1^0 + A_1^1 + A_2^0 + A_2^1} \tag{39}$$

where subscript 1 refers to the triangle 123 and subscript 2 to triangle 134 in Figure 6. For satisfying Eq. (18) the area A is taken as one-half the denominator in Eq. (39), that is, the average of the areas at the beginning and end of the time increment.

For use in the computer program, Eq. (39) is recast into the following form with the aid of Eqs. (27) - (31), (37) and (38):

$$\dot{\varepsilon}_x = \frac{u_{13}y^m_{24} - u_{24}y^m_{13}}{A^0 + A^1} \tag{40}$$

Similarly

$$\dot{\varepsilon}_y = \frac{v_{24}x^m_{13} - v_{13}x^m_{24}}{A^0 + A^1} \tag{41}$$

$$\dot{\varepsilon}_{xy} = \frac{u_{24}x^m_{13} - u_{13}x^m_{24} + v_{13}y^m_{24} - v_{24}y^m_{13}}{2(A^0 + A^1)} \tag{42}$$

$$\dot{\omega}_{xy} = \frac{u_{13}x^m_{24} - u_{24}x^m_{13} + v_{13}y^m_{24} - v_{24}y^m_{13}}{2(A^0 + A^1)} \tag{43}$$

The requirement given by Eq. (19) is met somewhat more readily in the computer program. The values of $\dot{\varepsilon}_x$ and $\dot{\varepsilon}_y$ are first determined from Eqs. (40) and (41), and the specific volume change is determined from calculations of the volume before and after a time step. The volume change is from a density calculation, which is in turn based on the mass conservation relations. The mass of an axisymmetric cell is computed from

$$M_s = \int \frac{d\theta}{3} \sum_i A_i \sum_j y_{ij} = \frac{2\pi}{3} \sum_i A_i \sum_i y_{ij} \tag{44}$$

where A_i is the area of the i^{th} triangle in the xy plane and y_{ij} are the radial positions of the vertices. For simplicity, $2\pi/3$ is dropped in the program and the mass is stored in the Z array as

$$Z = \frac{3\pi}{2} M \tag{45}$$

For the planar cells, the mass is simply

$$M = Z = \rho A_{xy} \tag{46}$$

Then during strain calculations, the density is determined by

$$\rho = \frac{Z}{A_{xy}} \tag{47}$$

for example, using Eq. (46). The relative volume change required in Eq. (19) is then

$$\frac{\Delta V}{V} = \frac{2(\rho_1 - \rho_2)}{\rho_1 + \rho_2} \tag{48}$$

where ρ_1 and ρ_2 are densities before and after the current time increment. With $\dot{\varepsilon}_x$, $\dot{\varepsilon}_y$, and $\Delta V/V$ known, $\dot{\varepsilon}_z$ is obtained from Eq. (19), and the volume constraint is satisfied exactly.

3.3 Energy Calculations

The internal energy is computed from the conservation of energy equation at two points. First, an approximate estimate is made just preceding the stress calculation; then a refined value is obtained following the stress calculation.

The conservation of energy expresses the balance between internal energy and strain energy:

$$E = E_o + V \sum_{ij} \sigma_{ij} d\varepsilon_{ij} \tag{49}$$

where E, E_o = internal energies at the end and beginning of the time increment

V = specific volume

σ_{ij}, ε_{ij} = tensor stress and strain values.

In the TROTT code, the first internal energy calculation immediately follows the determination of density and strain, but the only stresses available are those from the previous time step. In the computation, the stresses σ_{ij} are separated into a pressure and a deviator stress σ'_{ij}. With the introduction of the artificial viscous stress Q, the computer program form of Eq. (49) is

$$E = E_o + V(\sigma'_{xxo}\Delta\varepsilon_x + \sigma'_{yyo}\Delta\varepsilon_y + \sigma'_{zzo}\Delta\varepsilon_z + 2\sigma_{xyo}\Delta\varepsilon_{xy}) - (P_o + Q)(V - V_o) \tag{50}$$

where σ'_{xxo}, P_o, etc., are stresses and pressures from the previous time increment. The sign convention in Eq. (50) reflects the fact that stresses and strains are positive in tension, but pressures are positive in compression.

Following the stress computation, the energy computation is repeated, this time using the linear approximation

$$\frac{\sigma_{ij1} + \sigma_{ijo}}{2}\Delta\varepsilon_{ij} = \int \sigma_{ij} d\varepsilon_{ij} \tag{51}$$

where σ_{ij1} is stress from the current time. Then Eq. (49) becomes

$$E = E_o + V\left[\frac{\sigma_{xx1} + \sigma_{xxo}}{2}\Delta\varepsilon_x + \frac{\sigma_{yy1} + \sigma_{yyo}}{2}\Delta\varepsilon_y + \frac{\sigma_{zz1} + \sigma_{zzo}}{2}\Delta\varepsilon_z + (\sigma_{xy1} + \sigma_{xyo})\Delta\varepsilon_{xy}\right] - \left(\frac{P + P_o}{2} + Q\right)(V - V_o) \tag{52}$$

The energy approximation in Eq. (50) is used in the subsequent stress calculation. Normally, this energy approximation does not lead to serious errors because the energies are changing gradually in problems treated with TROTT. Very sharp shock fronts at high stresses would not be simulated accurately with the preceding energy calculation. The energy calculation in Eq. (52) is used to obtain the energy, which is stored in the cell array for the next calculational cycle.

3.4 Artificial Viscous Stress

An artificial viscous stress is required in finite-difference wave propagation calculations to smooth out shock waves so that the entire flow field can be treated by the conservation equations of continuous flow. In multidimensional calculations, a triangular artificial viscous stress is also required to combat certain types of cell distortion. Here we describe first the standard artificial viscosity and its implementation in the code.

The artificial viscous stress (Q) is added to the thermodynamic equilibrium stress (σ) from the constitutive relations to produce the nonequilibrium mechanical stress (T). The mechanical stress is therefore the total stress acting between masses and is the appropriate stress for the momentum calculations exhibited earlier. The artificial viscous stress represents real stresses occurring in the nonequilibrium states of a shock front, but the basis for computing Q is artificial because it depends on the computational cell size and on viscosity coefficients that are not derived from physical processes.

In TROTT the usual linear and quadratic forms of artificial viscosity are provided. Both are related to the rate of compression of the material and are zero while the material is extending. For positive density changes, the linear and quadratic stresses are

$$Q_1 = C_1 \, C_s \sqrt{A_{xy}} \; \frac{\Delta\rho}{\Delta t} \qquad (53)$$

$$Q_2 = \frac{C_o^2 A_{xy}}{\rho} \left(\frac{\Delta\rho}{\Delta t}\right)^2 \tag{54}$$

where

C_1 = coefficient of linear artificial viscosity

C_s = sound speed

C_o = coefficient of quadratic artificial viscosity.

The artificial stress Q is the sum of the linear and quadratic contributions from Eqs. (53) and (54).

The nominal values of the artificial viscosity coefficients are

C_1 = 0.15

C_o^2 = 4.0

These values are appropriate for most problems. If sharper definition of shock fronts is required, C_1 could be reduced to as low as 0.05. For more rapid smoothing of wave fronts for quasi-static problems, C_1 could be increased to 0.5.

The triangular artificial viscous stress is used to minimize a type of cell distortion termed hour-glassing (shown in Figure 7). Hour-glassing is a parasitic behavior that is not corrected by the normal momentum, strain, and constitutive relations previously outlined. The motion shown in Figure 7 gives rise to zero values of ε_x, ε_y, and ε_{xy}. Also, stresses in the cell acting on the coordinates would be applied equally to all four coordinates and could not simultaneously pull inward on points 1 and 2, and push out on 3 and 4 to correct the behavior.

The hour-glassing motion in quadrilateral cells represents two additional degrees of freedom that arise because of the averaging process used in calculating the strains (Section 3.2). A triangular cell does not exhibit hour-glassing because the 3 coordinate points have just six

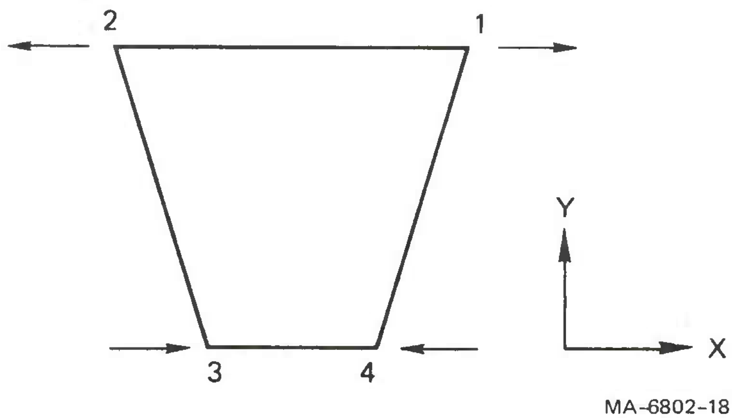


FIGURE 7 A QUADRILATERAL WITH COORDINATE VELOCITIES THAT LEAD TO HOUR-GLASSING

degrees of freedom that can be represented by two rigid body translations, one rotation (ω_{xy}) and three strains. The quadrilateral cell has eight degrees of freedom, but only the same six motions and strains as for the triangular cell are accounted for in the equations that provide the resistance to the motions. The triangular artificial viscosity provides resistance to the hour-glassing motion that arises because of the extra degrees of freedom.

The triangular artificial viscosity is calculated as part of the momentum relations instead of with the other stress calculations. These triangle stresses are computed as a function of the distortion of the triangle 2-3-4 (Figure 5), which is adjacent to point 3, the point of focus of the momentum calculations. From the strain rates in this triangle, the following stresses are computed according to the derivation of Wilkins (Ref. 1):

$$Q_{xx} = T_q \sqrt{A_{xy}}\, C_s \rho (2\dot{\varepsilon}_x - \dot{\varepsilon}_y) \tag{55}$$

$$Q_{yy} = T_q \sqrt{A_{xy}}\, C_s \rho (2\dot{\varepsilon}_y - \dot{\varepsilon}_x) \tag{56}$$

$$Q_{xy} = 3.0\, T_q \sqrt{A_{xy}}\, C_s \rho \dot{\varepsilon}_{xy} \tag{57}$$

where T_q = the dimensionless viscosity coefficient

A_{xy} = the area of the triangle

C_s = the sound speed

ρ = density

$\dot{\varepsilon}_x$, $\dot{\varepsilon}_y$, $\dot{\varepsilon}_{xy}$ = strain rates derived as in Section 3.2 for the triangle. Equations (55) to (57) are written so that the Q's are proportional to the appropriate deviator stress, assuming $\dot{\varepsilon}_z = 0$.

The triangle Q's are added into the force equations (8) and (9), to obtain

$$F_x = (T_{xy} + Q_{xy})A_{yy} + (T_{xx} + Q_{xx})A_{xx} \tag{58}$$

for Eq. (8) and a similar result for Eq. (9).

Now we can examine how the triangle Q works to inhibit hour-glassing. These stresses are computed separately for each of the near triangles around the four coordinate points in Figure 7. For instance, with the velocity configuration in Figure 7, Q_{xx} is tensile at points 1 and 2 and compressive at points 3 and 4. Thus, the Q forces tend to counteract the hour-glassing motion. With a coefficient of $T_q = 0.02$, a velocity pattern such as that in Figure 7 will be damped out in about 25 time steps.

3.5 Time Step Control

For the calculations to proceed in a stable manner, the time increment between cycles must be kept smaller than that given by the Courant-Friedrichs-Lewy conditions (Ref. 11). In this criterion the maximum permitted time increment is

$$\Delta t = \frac{\Delta x}{C_e} \tag{59}$$

where Δx = the minimum cell dimension

C_e = the local effective sound speed

In the computer program, the criterion in Eq. (59) is evaluated in five steps.

(1) Δx is computed as the minimum width for each cell.

(2) An effective modulus is computed, and from this a local sound speed, C'.

(3) A natural time step $\Delta t' = \Delta x/C'$ is computed for each cell.

(4) The minimum of all the time steps $\Delta t'$ is selected.

(5) The minimum time step is adjusted to account approximately for the triangle artificial viscosity.

The second and fifth steps are described in more detail below.

Here the effective sound speed is determined by summing the stiffness from all factors that contribute to the mechanical stress. The effective modulus for the time increment is given by a sum of ratios of stress increments divided by the strain increments:

$$M_e = \frac{\Delta P + 2Q}{-\frac{\Delta V}{V}} + \max \frac{\frac{2}{3}\Delta\sigma_i'}{\Delta\varepsilon_i'} \qquad (60)$$

where P = the change in pressure during the increment

Q = the artificial viscous stress

$\Delta V/V$ = the relative volume change

$\Delta\sigma_i'$ = the change in deviator stress in the i^{th} direction

$\Delta\varepsilon_i'$ = the deviator strain increment in the i^{th} direction.

The second term on the right-hand side of Eq. (60) is taken as the maximum value in the three principal directions. Because the maximum value of this term is given by the elastic relation, this term can be replaced by 4G/3, where G is the shear modulus. The factor 2 in the Q term arises because Q is computed at the half time step, providing twice the stiffness that would occur if Q were centered at the full time step. Then the effective sound speed for the cell is

$$(C')^2 = \frac{M_e}{\rho} = \frac{\Delta P + 2Q}{-\Delta V} + \frac{4G}{3\rho} \qquad (61)$$

It can be shown (Ref. 12) that Eq. (61) exactly represents the stability condition derived by Herrmann (Ref. 2) for linear and quadratic artificial viscosity. For small strains, C' is taken as the usual longitudinal sound speed.

To account for the additional stiffness associated with the triangle artificial viscosity, a further adjustment is made in the time step obtained using C'.

An approximate adjustment to account for the triangle artificial viscosity is derived by noting the parallel between the expressions for the triangle Q and the linear viscous term (Eqs. 55-57 and Eq. 53). The adjustment for the linear viscosity is given by Herrmann (Ref. 2) as

$$\Delta t = \frac{\Delta x}{C_s} \left[\sqrt{1 + C_1^2} - C_1\right] \tag{62}$$

Then we can replace C_1 by $3T_q$ (the factor of 3 occurs because $2\dot{\varepsilon}_x - \dot{\varepsilon}_y$ in Eq. 55 is three times the deviator strain rate) and neglect the T_q^2 term because T_q is very small. The final form of Eq. (59) is then

$$\Delta t = \min \left(\frac{\Delta x}{C'}\right)(1 - 3T_q) \tag{63}$$

This time step includes the effects of bulk stiffness, shear stiffness, and the three artificial visious stiffnesses. The foregoing equations are used in TROTT to determine the permissible time increments.

3.6 Slide Lines

A preliminary slide line capability has been incorporated into TROTT to permit slip of one material past another. Although several slide line problems have been run successfully, the coding has not been tested on arbitrarily complex problems. No opening and closing routine is present, no shear is transmitted across the slide line, and the lines are active from the beginning of the calculation (no provision for unzipping during

the calculation). Sliding can occur along lines of constant K or J but not along both simultaneously.

For a slide line between cells, two rows of coordinates are provided, one set for cells on either side. One side is designated the master and the other the slave side. The slave coordinate points are required to slide along the master cell boundaries, and need not coincide with the master coordinate points at any time. Because the slide line shape is determined by the master cells, the master side should be the material with the higher shear modulus and/or higher density. The forces for the momentum computations are computed from the stresses in both master and slave cells to determine the new velocities of the master coordinates. Only the forces on the slave side are used to move the slave coordinates, but then the slave coordinate positions are adjusted to avoid penetration of the master cells. This adjustment is made without testing for momentum conservation, so there may be some momentum loss along the slide line.

The K-slide treatment is designed to handle a slide along a line of nearly constant X, so the slave-side coordinate adjustments are of the X position only. The master coordinates are along K = KSLIDE - 1 and the slave coordinates are along K = KSLIDE, where KSLIDE is an input quantity. The J-slide case is for sliding along a line of nearly constant Y or radius; adjustments are made in the Y position only. The master coordinates are along J = JSLIDE and the slave coordinates are along J = JSLIDE - 1, where JSLIDE is an input quantity. Input information for the slide lines is provided in Section 5 and Appendix C.

4. MATERIAL MODELS

The material models provide the stress as a function of density, strains, internal energy, and other quantities. This section describes common material models or constitutive relations in SWEEPT. If other models are required, they are written as subroutines and called by SWEEPT for stress computations. The switching procedure used to select the appropriate model is also described below.

4.1 Standard Constitutive Models

In the standard material models, the stress tensor is separated into a pressure and a deviator tensor. The pressure is the average stress

$$P = \frac{1}{3} \sum_i \sigma_{ii} \tag{64}$$

and the stress deviator elements are

$$\sigma'_{ij} = \sigma_{ij} - P\delta_{ij} \tag{65}$$

where σ_{ij} are stress tensor elements and δ_{ij} is the Kronecker delta. The pressure is usually given as a function of density and internal energy. The deviator stress is computed by elastic-plastic relations, which may include thermal softening, rate-dependent effects, and work hardening. Since TROTT is intended primarily for mechanical problems at stress levels common in engineering structures, the standard pressure model does not include melting and vaporization, and the deviator model does not include thermal softening. However, these effects could be added in special material models subroutines. The standard pressure and deviator models are presented below.

4.1.1 Standard Pressure Model

The pressure is computed from a simplified form of an equation of state, the locus of all possible thermodynamic equilibrium states for a substance. Each state is a set of values of the thermodynamic quantities: stress tensor, specific volume, entropy, specific internal energy, and temperature. In the simplified equation of state used in TROTT and in most wave propagation codes, the only variables considered are pressure (P) (the deviator components of stress are treated separately), specific volume (V) or density ($\rho = 1/V$), and internal energy (E). The equation of state is then

$$P = P(E,V) \tag{66}$$

which defines a surface or locus of points in energy-pressure-volume space.

An equation of state represents equilibrium states. Therefore, as a material undergoes gradual changes, such as heating or compression, the successive states describe a path on the equation-of-state surface. If the material is compressed by passing through a steady-state shock front, the initial and final states lie on the P-V-E surface. These initial and final states are connected by a straight line, the Rayleigh line, which does not lie on the surface, but above the P-V-E surface. Generally, equations of state describe the material behavior in solid, liquid, and gaseous phases, but the pressure model in TROTT represents only solid states.

The Mie-Grüneisen equation is used in TROTT to determine the pressure.

$$P = P_{REF} + \frac{\Gamma}{V}(E - E_{REF}) \tag{67}$$

where

P_{REF}, E_{REF} = coordinates of a point on some reference curve at the same specific volume V

Γ = the Grüneisen ratio.

This expression provides a means for extending the information of a known P-V relationship (such as the Hugoniot) to other values of internal energy. Because the Hugoniot is the P-V relation that is most likely to be known, the computations are constructed with the Hugoniot as the reference curve. (The Hugoniot curve used here is the locus of final pressure, energy, and volume points reached by a shock front traveling into material under standard pressure and temperature conditions.) The Hugoniot P-V equation is presumed to be in the form

$$P_H = C\mu + D\mu^2 + S\mu^3 \tag{68}$$

where

$$\mu = \frac{\rho}{\rho_o} - 1 = \frac{V_o}{V} - 1$$

ρ_o , V_o = the initial solid density and specific volume

C,D,S, = coefficients with the dimensions of pressure

C = the bulk modulus at low pressures.

The internal energy along the Hugoniot is

$$E_H = \frac{1}{2} P_H(V_o - V) \tag{69}$$

Here the initial internal energy is assumed to be zero and the Hugoniot is concave upward throughout so that the shock follows a single Rayleigh line. Combining Eqs. (67) through (69) provides the pressure relation used in the computer program

$$P = (C\mu + D\mu^2 + S\mu^3)\ (1 - \Gamma\mu/2) + \Gamma\rho E \tag{70}$$

This calculation is performed following the density and strain computation and the approximate evaluation of E from Eq. (50).

4.1.2 Standard Deviator Stress Model

The deviator stress is the part of the stress tensor that arises because of the material's resistance to shearing deformation. In TROTT the standard model for deviator stress accounts for elastic response and plastic flow according to perfect plasticity. Here the relations are developed in a general form applicable to planar or axisymmetric flow.

Elastic Relations. The elastic relations between deviator stress and strain are cast in the following form

$$\sigma'_{ij} = 2G(\varepsilon^E_{ij} - \frac{\delta_{ij}}{3} \Sigma\varepsilon^E_{ii}) \tag{71}$$

$$= 2G\varepsilon'^E_{ij} \tag{72}$$

where

σ'_{ij} = the deviator stress

ε^E_{ij}, ε'^E_{ij} = total and deviatoric elastic strains

δ_{ij} = the Kronecker delta.

The deviator strain is defined as follows (as noted by comparing Eqs. 71 and 72):

$$\varepsilon'^E_{ij} = \varepsilon^E_{ij} - \frac{\delta_{ij}}{3} \Sigma\varepsilon^E_{kk} \tag{73}$$

In elastic problems, all the strain is elastic, but in plastic cases, the total strain is separated into elastic and plastic components.

$$d\varepsilon_{ij} = d\varepsilon^E_{ij} + d\varepsilon^P_{ij} \tag{74}$$

Plastic Relations. The Reuss or incremental plasticity relations are considered here. Yield occurs when the effective stress reaches the yield strength. The effective stress is defined by

$$\bar{\sigma} = \sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}} \tag{75}$$

where the repeated subscripts indicate summation. The yield criterion is simply

$$\bar{\sigma} = Y \tag{76}$$

where Y is the yield strength. The Reuss flow rule indicates that the deviator stress in any direction is proportional to the plastic strain in that direction:

$$d\varepsilon^P_{ij} = \sigma'_{ij}d\lambda \tag{77}$$

where $d\lambda$ is a proportionality constant. Now Hill (Ref. 13) defines a scalar plastic strain quantity as follows:

$$d\bar{\varepsilon}^P = \sqrt{\frac{2}{3}d\varepsilon^P_{ij}d\varepsilon^P_{ij}} \tag{78}$$

As before, the repeated subscripts indicate summation. When we square Eq. (77) and make use of the definitions of $\bar{\sigma}$ and $d\bar{\varepsilon}^P$, then

$$d\bar{\varepsilon}^P = \frac{2}{3}\bar{\sigma}d\lambda \tag{79}$$

and

$$d\varepsilon^P_{ij} = \sigma'_{ij}\frac{3d\bar{\varepsilon}^P}{2\sigma} \tag{80}$$

To obtain a solution for an increment of strain, we compute first a nominal stress σ'^N_{ij} that would occur if the strain were entirely elastic.

$$\sigma'^{N}_{ij} = 2G(\varepsilon'^{E}_{ijo} + \Delta\varepsilon'_{ij}) = 2G(\varepsilon'^{E}_{ijo} + \Delta\varepsilon'^{E}_{ij} + \Delta\varepsilon^{P}_{ij})$$

$$= 2G(\varepsilon'^{E}_{ij} + \Delta\varepsilon^{P}_{ij}) \qquad (81)$$

where

ε'^{E}_{ijo}, ε'^{E}_{ij} = elastic strains before and after the current strain increment

$\Delta\varepsilon'_{ij}$, $\Delta\varepsilon'^{E}_{ij}$, $\Delta\varepsilon^{P}_{ij}$ = total, elastic, and plastic strain increments.

Through the use of Eqs. (72) and (80), the strains in the third equation of (81) can be replaced by expressions in σ'_{ij}.

$$\sigma'^{N}_{ij} = \sigma'_{ij}\left(1 + \frac{3G\Delta\bar{\varepsilon}^{P}}{\bar{\sigma}}\right) \qquad (82)$$

Note that by using Eq. (80) we are relating the plastic strain increment to the stress σ'_{ij} at the end of the time step instead of to the average stress over the step. This approximation is satisfactory for small changes in stress direction. If both sides of Eq. (82) are squared and terms are summed to form a quantity $\bar{\sigma}^{N}$ in analogy to the definition of $\bar{\sigma}$ in Eq. (75), then we obtain

$$\bar{\sigma}^{N} = \bar{\sigma}\left(1 + \frac{3G\ \Delta\bar{\varepsilon}^{P}}{\bar{\sigma}}\right) \qquad (83)$$

Combining Eqs. (82) and (83) and using the yield condition (76), gives a solution for σ'_{ij}.

$$\sigma'_{ij} = \sigma'^{N}_{ij}\ \frac{Y}{\bar{\sigma}^{N}} \qquad (84)$$

The elastic strain can be found from σ'_{ij} and the effective plastic strain is obtained from Eq. (83) with $\bar{\sigma} = Y$.

4.2 Switching for Complex Material Models

Constitutive or material models may take many forms besides the standard types presented above. Some of the available nonstandard models are introduced here and the portion of SWEEPT calling them in the code is described. Procedures for inserting new models are described in Appendix A.

Our work in porous materials, fracture, composites, and explosives has led us to require the use of very general material models. TROTT and SRI PUFF models were constructed to reflect these requirements. For example, in fracture calculations it should be possible to treat the material with a continuum model up to incipient fracture and then transfer to a fracture model. Composites should be simulated either by a single model or by a combination of models representing the constituents. If pressure and deviator stresses are treated separately for the material, then it should be possible to combine any pressure model with any deviator model. These general requirements have been followed in setting up model types.

At present five model types are accounted for in TROTT:

- Composite, for multiconstituent materials. Total stresses are computed.
- Fracture. The models are called after a criterion is reached showing that fracture has begun. Total stresses are computed.
- Porous. Either total stress or pressure is computed, depending on the model. At consolidation, transfer may occur to a continuum model.
- Deviator. Only deviator stresses are computed, so one of these models is used in conjunction with a pressure model.
- Pressure. Only pressure is computed. Explosives are treated under this type.

The subroutine SWEEPT was constructed to serve as a switch between the various subroutines computing pressure, deviator stress, and total stress. The flow chart in Figure 8 emphasizes these stress-switching features. The material models that are currently available are listed

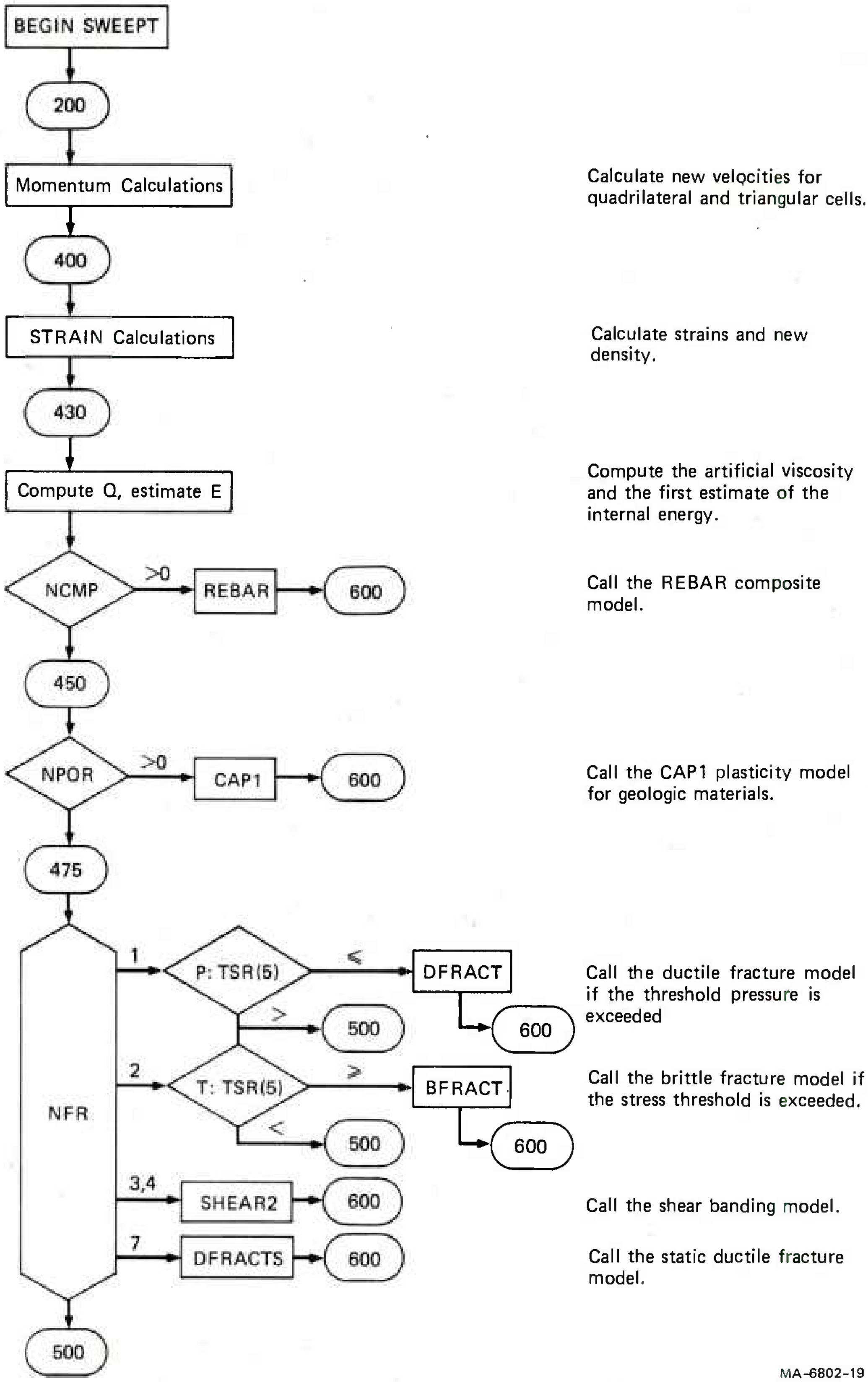
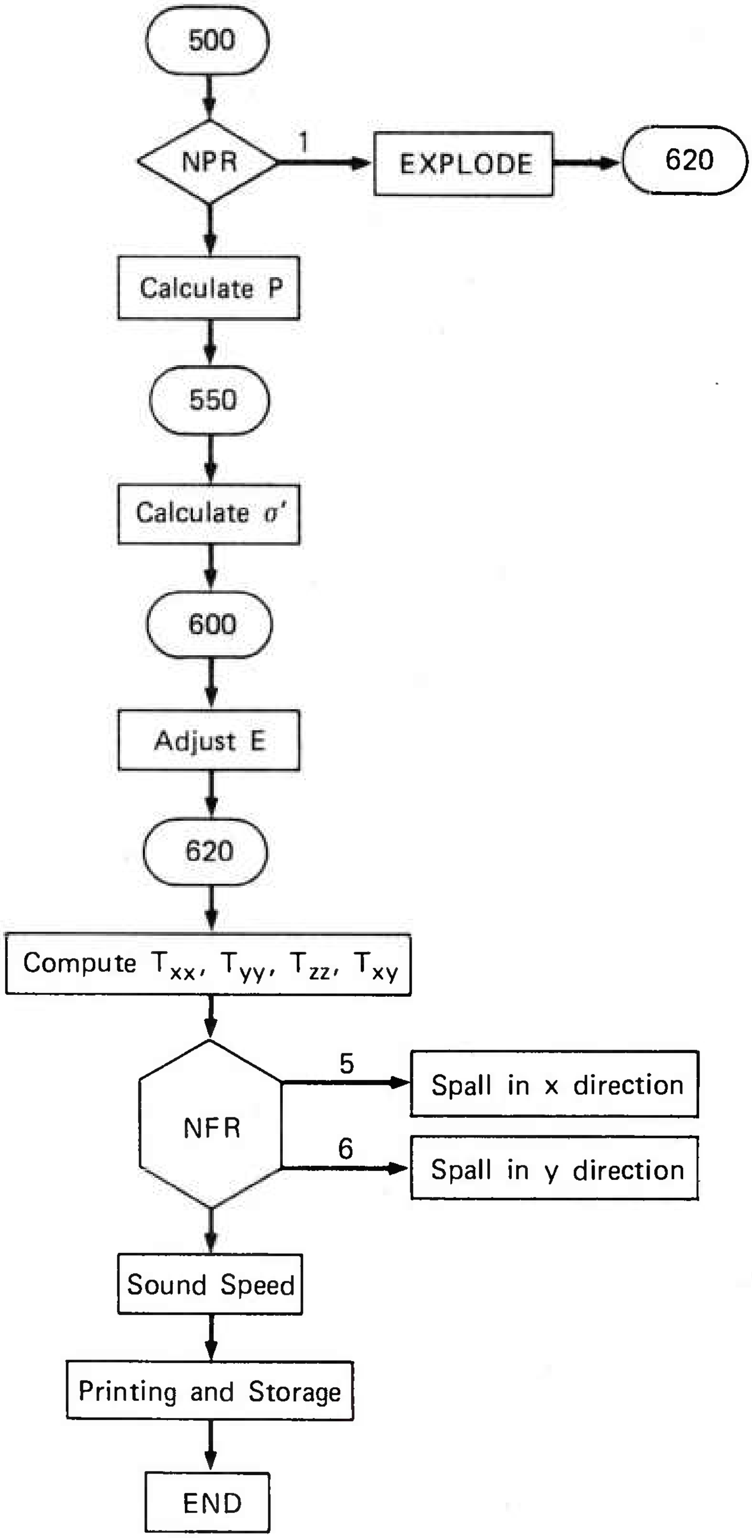


FIGURE 8 FLOW CHART FOR SWEEPT EMPHASIZING THE PROCEDURE FOR SWITCHING BETWEEN MATERIAL MODELS



Call EXPLODE to compute pressure and energy in explosive gases

Compute pressure from the Mie-Gruneisen equation of state

Compute deviator stress from and elastic, perfectly plastic model

Recompute internal energy based on the latest values of stress

Compute total stresses from pressures, deviators and artificial viscosity

Check for spall in the x or y directions. Reset the stresses if spall has occurred

Compute the sound speed and permissible time step

Print an edit and store for the historical listings

MA-6802-20

FIGURE 8 FLOW CHART FOR SWEEPT EMPHASIZING THE PROCEDURE FOR SWITCHING BETWEEN MATERIAL MODELS (Concluded)

in the figure and in Section 2. The list in Section 2 also shows where to find more information about each model. The large library of material models associated with the SRI PUFF 8 program may be readily added to TROTT. In fact, of the material model subroutines now in TROTT, only EXPLODE differs from the corresponding routine in PUFF.

4.3 Spall Calculations

In two-dimensional calculations it may be necessary to permit layers of materials to separate during the calculation. An approximate representation of such separation is provided by allowing the stress in the cells along one side of the spall or separation line to reduce to zero in a direction normal to the spall line. Such a separation procedure is provided in TROTT.

Spall is provided for in a cell by representing the material in the cell with a fracture model, labeled by the indicator NFR.

NFR = 5 spall is the x or axial distance
= 6 spall in the y or radial direction

Spall is not permitted in both directions at once. The tensile strength (positive) is read into the TSR array as TSR(M,1) during reading of the material property data.

The spall calculations follow the determination of stress from the usual stress-strain relations and construction of the total stress quantities T_{xx}, T_{yy}, T_{zz}, and T_{xy}. First the possibility of spall is checked by comparing either T_{xx} or T_{yy} (as indicated by NFR) with the spall strength. If the tensile stress exceeds the strength, spall occurs. For this analysis, we assume that the tensile stresses were T_{11}, T_{22}, T_{33}, and T_{12} and that the spall is in the first direction. To produce the spalled state, we apply a compressive stress of $T = - T_{11}$ in the first direction. The conditions of the spall are like those in a uniaxial strain test, because strain occurs only in the first direction. Hence the pressure and deviator stress changes in the spall direction are

$$\Delta P = \frac{C}{C + \frac{4}{3}G} T \tag{85}$$

$$\Delta\sigma' = \frac{\frac{4}{3}G}{C + \frac{4}{3}G} T \tag{86}$$

As usual the deviators in the other directions are

$$\Delta\sigma'_{22} = \Delta\sigma'_{33} = -\frac{1}{2}\Delta\sigma'_{11} \tag{87}$$

Finally, the residual stress state is obtained by adding the effects of this recompression in the spall direction to the existing stresses.

$$\begin{aligned} T_{11} &\rightarrow T_{11} + T = 0 \\ T_{22} &\rightarrow T_{22} + \Delta P + \Delta\sigma'_{22} \\ T_{33} &\rightarrow T_{33} + \Delta P + \Delta\sigma'_{33} \end{aligned} \tag{88}$$

and the shear stress T_{12} is set to zero. The separation calculation is repeated at each cycle so that recombination is permitted at any time.

5. INITIALIZATION

The LAYOUTT subroutine is called at the beginning of each problem to read in all data and initialize the variables. The sequence of operations in LAYOUTT is

- Fill the array storage with initial values, usually zero.
- Read the general running and printing instructions for the problem.
- Read properties for each material.
- Read the grid layout data and construct the layout by initializing all array storage.
- Print the initial layout.

This section describes the general rules governing input and derives the equations for the layout. Several sample input decks are shown in Appendix C. All input information follows these guidelines:

- Each card or group of cards is labeled for ease of identification. For example, equation-of-state lines begin with the identifier "EQST = ". In most cases the identifier is optional and only aids the user in keeping the data in order.
- Each input line is read and then printed immediately in the same format (echo printing) so that the first page of printout looks like the input deck.
- The minimum amount of data is used for each problem. For example, the required data for a material are contained on just two lines. On the first line are indicators that show whether more lines are required because of special models used for the material.

The following subsections decribe three sets of data cards that are used for each problem: general running data, materials data, and grid layout. A sample of a complete input deck is shown in Figure 9.

```
NO 16, CONC IMP, 22.34M/S, FULL PROJ., MOMENTUM CHECK
NSTAR    0 NPLOT  999 NOUMP 999 IMAX= 600 IPRIN 100 JPRIN    4 NEXEO 600
IJBUNO   2 NBLOCK  16 NMTRLS   5 NJED=   8
TS=          2.000E-04 IVTYPE =            -1 NV8LK =          1
COSQ=        4.000E+00 CLIN         2.500E-01 TRIQ=       0.020E+00
KSLIOE   0 JSLIOE  0
LIST =    KJ/KG      KBAR       CM          M/SEC
CAL  =       1.000E-07 1.000E-09 1.000E+00 1.000E-02
JPR  =         200   202   300   302   400   402   500   502
JEOT,K,J=        1317  2      1317  3      1317  4      1323  2      1323  3      1323  4      1327  8
                 1330  8
```

GENERAL RUNNING DATA

```
IMPACTOR STEEL          RHOS=            7.85E0 CFP=  000 OPY  = 001 NVAR  =  2
EQSTC=       1.5889E12  5.170E12  7.360E10     1.69E0     0.25E0   5.170E13
YIELO=       1.030E+10  8.188E11

REBAR STEEL             RHOS=            7.85E0 CFP=  000 DPY=  001 NVAR=   2
EQSTC=       1.5889E12  5.170E12  7.360E10     1.69E0     0.25E0   5.170E13
YIELO=        1.030E10  8.188E11

CONCRETE                RHOS  =       2.85 E0    CFP  = 004 OPY  = 000 NVAR  =  5
EQST  =      2.830E+11 0.             1.000E+11 2.000E+00 .25       0.
RHO  =       2.22E0      AMU  =       2.033E+11
AK  =        7.000E+10 AK2  =      -.5500E+02 MUP  =       5.250E+10 MUP2  =       .1250E+03
MC  =        1.040E+09-8.300E+08 2.702E+09 2.500E+08 1.000E0
SCRIT  =     2.000E+07 OAMG(M)  =  1.000E-03
EVP  =              0.-1.200E-02-3.500E-02-5.000E-02-2.230E-01
NREG  =               4 NPRCAP  =         0 P1  =       -3.500E+08 W2  =       1.25
P2  =      -1.000E+09 OELP  =            0.
P2  =      -2.400E+09 OELP  =            0.
P2  =      -3.400E+09 DELP  =            0.
P2  =      -1.533E+10 DELP  =            0.

REBAR                   RHOS=         2.5015E0 CFP=  100 OPY  = 000 NVAR  = 13
EQSTC=        1.576E11          0.0          0.0       2.0E0      0.25E0          0.0
FS=             0.05E0 THET=                 0.0 IMC=                3 IMS=             2

ALUMINUM                RHOS  =       2.7         CFP=  000 OPY  = 001 NVAR  =  2
EQST  =      6.670E+11 1.000E+12 1.220E+11 2.04E      0.25E      0.
YIELO  =     3.210E+09 2.670E+11
```

MATERIALS DATA

```
(1)    K=    16    24    X=      7.62        17.78       17.78       7.62       MAT  =   1
       J=     1     4    Y=      0.          0.          1.111       1.111
(2)    K=     6     8    X=      2.54        3.556       3.556       2.54       MAT  =   3
       J=     1     4    Y=      0.          0.          1.111       1.111
(3)    K=     8     9    X=      3.556       4.064       4.064       3.556      MAT  =   4
       J=     1     4    Y=      0.          0.          1.111       1.111
(4)    K=     9    13    X=      4.064       6.096       6.096       4.064      MAT  =   3
       J=     1     4    Y=      0.          0.          1.111       1.111
(5)    K=    13    14    X=      6.096       6.604       6.604       6.096      MAT  =   4
       J=     1     4    Y=      0.          0.          1.111       1.111
(6)    K=    14    16    X=      6.604       7.62        7.62        6.604      MAT  =   3
       J=     1     4    Y=      0.          0.          1.111       1.111
(7)    K=     6     8    X=      2.54        3.556       3.556       2.540      MAT  =   3
       J=     4    26    Y=      1.111       1.111       12.7        12.7
(8)    K=     8     9    X=      3.556       4.064       4.064       3.556      MAT  =   4
       J=     4    26    Y=      1.111       1.111       12.7        12.7
(9)    K=     9    13    X=      4.064       6.096       6.096       4.064      MAT  =   3
       J=     4    26    Y=      1.111       1.111       12.7        12.7
(10)   K=    13    14    X=      6.096       6.604       6.604       6.096      MAT  =   4
       J=     4    26    Y=      1.111       1.111       12.7        12.7
(11)   K=    14    16    X=      6.604       7.62        7.62        6.604      MAT  =   3
       J=     4    26    Y=      1.111       1.111       12.7        12.7
(12)   K=     1     6    X=      0.          2.54        2.54        0.         MAT  =   3
       J=    14    26    Y=      8.89        6.378       12.7        12.7
(13)  K  =   24    26   X  =     17.78       19.685      19.685      17.78      MAT  =   5
      J  =    1     4            0.          0.          1.111       1.111
(14)  K  =   24    26   X  =     17.78       19.685      19.685      17.78      MAT  =   5
      J  =    4     7   Y  =     1.111       1.111       2.475       2.475
(15)  K  =   24    26   X  =     17.78       19.685      19.685      17.78      MAT  =   5
      J  =    7     8   Y  =     2.475       2.475       3.1496      3.1496
(16)  K  =   26    37   X  =     19.685      33.02       33.02       19.685     MAT  =   5
      J  =    7     8   Y  =     2.475       2.475       3.1496      3.1496
```

CELL AND COORDINATE LAYOUT

```
  JU=             4   KU  =            16   UZERO  =   -2.234E03
7/8/9
```

VELOCITY DATA

FIGURE 9 SAMPLE INPUT DECK FOR CONCRETE IMPACT PROBLEM

5.1 Input of General Running Controls

The first set of data identifies the computation and determine the length of the computation, the printing during and following the computation, the number of materials, and the overall geometry of the problem.

The second line contains NSTART, NPLOT, NDUMP, IMAX, IPRINT, JPRINT, NEXED, and NOBLQ. NSTART is the file number for restarting and is zero for a new problem (see Section 5.4). NPLOT is the frequency in cycles for writing a file containing data for an x,y plot. NDUMP is the frequency in cycles for writing a restart dump (see Section 5.4). IMAX is the maximum number of cycles permitted. IPRINT is the frequency in cycles for printing an edit or for listing the current status of major variables for each cell and coordinate. JPRINT is the number of special groups of edits required. For each group there is a JP1 and JP2, the cycles at which edits will begin and end. Within the range of each group, edits are printed at each cycle. JPRINT is used mainly to study difficulties that arise late in a computation. NEXED indicates the frequency of extra edits listing all the cell variables not normally listed in an edit. NOBLQ is an indicator for an impact of a block onto a smooth, nonmoving boundary (used for oblique ballistic impacts). If NOBLQ is nonzero, the angle of the boundary, ANGLE, is read on a line between the usual second and third lines.

The third line contains IJBUND, NBLOCK, NMTRLS, NJED, IPRIND and NEXTRA. IJBUND determines the geometry and boundary conditions as shown in Table 1. The grid layout information is inserted in the form of NBLOCKS of data, each block describing a quadrilateral in X,Y, space. The number of materials is NMTRLS. The number of historical listings requested in NJED. IPRIND indicates a request for the special print options, KSKIP, KFULL, KPMAX, KPMIN, JPMAX, and JPMIN, which limit the amount of printing in edits. A nonzero NEXTRA calls for a special input of data through the EXTRAT subroutine. If indicated, EXTRAT is called twice: at the end of reading the material data and just before the layout listing.

Table 1

DEFINITIONS OF IJBUND AND IVTYPE

- IJBUND -

Geometry		
Axisymmetric	Planar	Boundary Conditions*
1	-1	Fixed y velocity at J=Jmin and Jmax
2	-2	Fixed y velocity at J=Jmin only
-	-3	All edges free
4	-4	Fixed y velocity at J=Jmin, x velocity at K=Kmin and Kmax
5	-5	Fixed y velocity at J=Jmin and Jmax, x velocity at K=Kmin
9	-9	Special boundary conditions specified by the user as described in Appendix G.

Notes: Positive values of IJBUND denote an axisymmetric geometry with x axial, y radial, and z circumferential. Negative IJBUND values denote a plane strain geometry with x and y in the plane and z in third (zero strain) direction.

- IVTYPE -

Value	Meaning
0	No velocity initialization
1	Velocity is initialized for all J up to K = KU with an interface condition at K = KU
2	Velocity is initialized in NVBLK quadilateral blocks.
-1	Velocity is initialized for all J and from K = KU to Kmax. The interface condition is at KU.

*All minimum and maximum values not mentioned are free.

The fourth line contains the problem stop time TS, the velocity indicators IVTYPE and NVBLK, and KCHEK. IVTYPE is defined in Table 1. NVBLK is the number of quadrilateral blocks used in the velocity initialization for IVTYPE = 2. Initial wave propagation calculations are made from K = 1 to KCHEK, instead of from 1 to KMAX.

The fifth line contains the coefficients for the quadratic, linear, and the triangular artificial viscosities: CQSQ, CLIN, and TRIQ.

The sixth line contains slide line controls (KSLIDE and JSLIDE), a special boundary condition indicator (NBND), and an indicator (ICAL) for the units used in printing the IPRINT listings. KSLIDE and JSLIDE determine the location of slide lines -- only one can be nonzero. NBND is the number of special boundary conditions. For NBND nonzero, NBND lines are read in next containing the special boundary data: IBDK1, IBDK2, IBDJ1, IBDJ2, IBDX, IBDY, XFIX, and YFIX. These parameters and the special boundary conditions are described in Appendix G. A nonzero value of ICAL calls for reading two lines containing calibration information for the IPRINT listings. These additional lines contain the alphanumeric parameters LISTE, LISTS, LISTX, and LISTXD and the constants CALE, CALS, CALX and CALXD, which are defined in Table 2. Each of these parameters is initialized in LAYOUTT with the value given in the table. If the user wishes different units, he should set ICAL to one, and read in the necessary lines. For example, to use kbar as the stress unit, LISTS is read in as KBAR, and CALS is set to 1.E-9. (The internal units of the code are dyne, centimeter, gram and second.)

For nonzero values of JPRINT, the next line is a special line containing JP1 and JP2 values.

The next input lines contain the detailed requests for historical listings of specific variables. Each request is composed of three integers labeled JEDT(I), JEDK(I), and JEDJ(I). JEDT is the type of variable, whereas JEDK and JEDJ are the K,J locations of the cell or coordinate. The types are defined in Table 3 along with some sample input. The type number is used in SWEEPT to obtain the required variable from the COM array. For the standard variables, the type number can be

obtained from the equivalence statement for the COM array. For other variables, see the discussion of NVAR and COM in Appendix B. The JED variables must be read in the order in which the K,J coordinates will be encountered in the calculation: JEDT, JEDK, and JEDJ groups must be in order of increasing JEDK, and for groups with the same JEDK, and the JEDJ must be in increasing order. For the same JEDK and JEDJ values, groups with different JEDT can be in any order.

If IPRIND is nonzero, a special print-control line is read at this point, completing the input of general running data.

5.2 Material Properties

Each material is described by data on a series of lines following the general running information. These lines contain

1. Material name, solid density, a series of flags (NCMP, NFR, NPOR, NDS, NPR, NYAM), NVAR, and NTRI.
2. Solid equation-of-state parameters: EQSTC, EQSTD, EQSTE, EQSTG, EQSTH, EQSTS, and PMIN.
3. Special data required for composite, fracture, porous, deviator, or pressure models.
4. Yield data (yield strength, shear modulus, and work-hardening modulus) read in for nonzero values of NYAM.

The parameters mentioned above are all defined in the Glossary, Appendix F. The flags NCMP to NPR show what data are required in the lines under item 3. NYAM controls the reading of item 4. NVAR is the number of extra variables required in addition to the standard 17 (the first 17 listed in Table 3). For example, a material with a yield model requires NVAR = 2. NVAR is described further in Appendix B. NTRI is a flag indicating that all quadrilaterial cells of the material are to be divided into triangles.

The input for the special models takes different forms depending on the model. Section 2 lists references to the descriptions of each special model.

Table 2

CONVERSION OF UNITS FOR IPRINT LISTINGS

Parameter	Initialized Value	Quantity Affected	Internal Units
CALE	1.E-7	internal energy	erg/g
CALS	1.E-7	stress, pressure	dyn/cm^2
CALX	1.	X, Y location	cm
CALXD	1.E-2	velocity	cm/sec
LISTE	KJ/KG	internal energy	
LISTS	MPA	stress, pressure	
LISTX	CM	X, Y location	
LISTXD	M/SEC	velocity	

Table 3

TYPE DESIGNATIONS FOR HISTORICAL LISTINGS

JEDT Value	Variable
1	X, Eulerian axial position
2	Y, Eulerian radial position
3	XD, $\dot{X}$ or axial velocity
4	YD, $\dot{Y}$ or radial velocity
5	Variable location for triangular cells
6	A, cell area in the x-y plane
7	Z, cell mass (constant)
8	D, cell density
9	SXX, deviator stress in the x direction
10	SYY, deviator stress in the y direction
11	SZZ, deviator stress in the z direction
12	TXY, shear stress on the xy plane
13	TXX, total mechanical stress in the x direction
14	TYY, total mechanical stress in the y direction
15	TZZ, total mechanical stress in the z direction
16	P, pressure
17	E, internal energy
18	H, indicator
19	YY, yield strength
L	COM(L), extra variable
-45	$\bar{\varepsilon}$, $\sqrt{2/9\left[\left(\varepsilon_x - \varepsilon_y\right)^2 + \left(\varepsilon_y - \varepsilon_z\right)^2 + \left(\varepsilon_x - \varepsilon_z\right)^2 + 6\varepsilon_{xy}^2\right]}$, a scalar deviator strain
-46	Σ EXXH, cumulative strain in the x direction
-47	Σ EYYH, cumulative strain in the y direction
-48	Σ EZZH, cumulative strain in the z direction
-49	Σ EXYH, cumulative strain in the xy direction
-50	Q, artificial viscosity
-51	SXX-P, thermodynamic stress in the x direction
-52	SYY-P, thermodynamic stress in the y direction

Table 3 (Concluded)

JEDT Value	Variable
-53	SZZ-P, thermodynamic stress in the z direction
-54	Force in the x direction at the K-th row
-55	$-2 \ln (Y_{K,Jmax}/Y_o)$, an areal strain for axisymmetric problems

Sample Input:

T K J*	T K J	T K J	T K J	T K J	T K J	T K J
8 2 5	13 2 5	51 2 5	8 2 7	13 2 7	8 3 4	13 3 4
8 3 6	13 3 6	13 5 2	8 5 2	812 5	1512 5	151213
1413 2	1413 6	1524 2	1424 2			

*The labels T K J indicate JEDT, JEDK and JEDJ. This label line is not included in input.

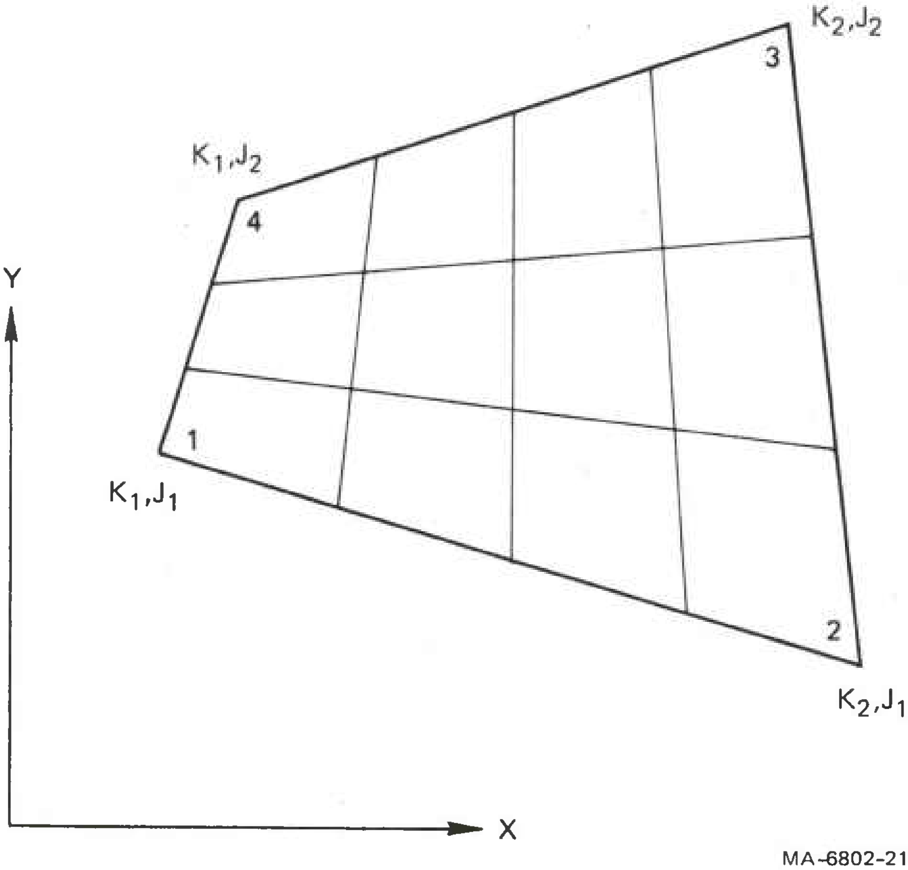


FIGURE 10 A QUADRILATERAL BLOCK OF CELLS USED IN THE GRID LAYOUT

5.3 Grid Layout and Velocity Initialization

The grid for the computations is entirely laid out in quadrilateral blocks. For each block the J, K, x, and y values are provided for the four corner points, and the material number in the cells is designated. The information is provided on two input lines as follows:

K_1, K_2, x_1, x_2, x_3, x_4, MAT

J_1, J_2, y_1, y_2, y_3, y_4

The J and K values are Lagrangian coordinate numbers as shown in Figure 10. The Eulerian coordinates x and y of the four corners are inserted in the counterclockwise order for all cells in the block. From this input, the intermediate x and y coordinate points are computed from the expression

$$x_{K,J} = \frac{[x_1(J_2 - J) + x_4(J - J_1)]\ (K_2 - K) + [x_2(J_2 - J) + x_3(J - J_1)](K - K_1)}{(J_2 - J_1)\ (K_2 - K_1)} \tag{89}$$

and a similar one for $y_{K,J}$. In the resulting grid, all lines are straight and the increments of x (or y) are equal along any line.

The velocities can be initialized either by designating a single velocity $\dot{x}$ for the moving portion of the object or by designating blocks as in the grid layout. For the single velocity layout, the required information is J_u, K_u, and U_z, where J_u is usually the largest J value (outer radial boundary of the moving object), and K_u is the K value at the interface between moving and nonmoving parts of the object. For IVTYPE = 1, $\dot{x}$ velocities are initialized to U_z for $K > K_u$; and for IVTYPE = -1, $\dot{x} = U_z$ for $K < K_u$. Along the interface $K = K_u$, the velocity $\dot{x}$ is initialized to a value that preserves the total momentum approximately. For this computation, we obtain the sum M_p of the masses in the projectile cells (from J = 2 to J_u) along the interface and the

mass M_T of the corresponding cells along the target. Then the interface velocity $\dot{x}$ initialized along $K = K_u$ is

$$U_{int} = \frac{U_z M_p}{M_p + M_T} \tag{90}$$

If cells are properly matched across the interface so that the crossing time of cells are equal in the x direction, the interface velocity given by Eq. (90) is approximately the velocity reached in a one-dimensional impact. By starting with a good estimate of the velocity U_{int}, we minimize the stress oscillations that usually appear in impact calculations. If the entire layout is to be initialized at the same velocity, as for an oblique impact on a rigid wall, then J_u can be set to zero and K_u is set to zero (for IVTYPE = -1) or KMAX +1 (for IVTYPE = 1).

In the second type of velocity initialization, the user provides the velocity distribution by quadrilateral blocks (NVBLK of them) as in the grid initialization. The velocities at all points in the block are then initialized so that there is a linear variation of velocity with distance whenever possible. The equation used for the velocity interpolation is

$$\dot{x}_{K,J} = \frac{\left[\dot{x}_{K1,J1}(x_{K2,J1} - x_{K,J1}) + \dot{x}_{K2,J1}(x_{K,J2} - x_{K1,J1})\right](y_{K,J2} - y_{K,J})}{(x_{K2,J1} - x_{K1,J1})(y_{K,J2} - y_{K,J1})}$$

$$+ \frac{\left[\dot{x}_{K2,J2}(x_{K,J2} - x_{K1,J2}) + \dot{x}_{K1,J2}(x_{K2,J2} - x_{K,J2})\right](y_{K,J} - y_{K,J1})}{(x_{K2,J2} - x_{K1,J2})(y_{K,J2} - y_{K,J1})} \tag{91}$$

A similar equation is used for the velocity in the y direction, $\dot{y}$. The resulting velocity distribution is linear with distance along straight K and J lines in the block.

5.4 Restart Procedure

For long calculations it is convenient to be able to perform the computations in several sections. At the end of each section of the calculation, the program is stopped, all the information on the current status is stored, and the computed results are examined. Then changes are made in the input as required, the stored information is read in again and the calculation is restarted.

In preparation for a restart the parameter NDUMP is set to the frequency in cycles at which a restart file should be written. At cycles which are multiples of NDUMP and at the last cycle, a restart record is written onto file 9 in TROTT. The restart record contains the COM, LVAR and MM arrays plus the parameters JMAX, JMIN, KMAX, KMIN, and TYME. The programmer must save file 9 at the end of the calculation.

To restart from the stored information, NSTART is set to the number of the record to be used for restarting. The restart records are read from file 1; therefore, the programmer must prepare for the restart by assigning the name "file 1" to the restart file. New restart records will be written on file 9 as before. For a restart, the input deck includes the General Running Data and Materials Data labeled in Fig. 9. Hence these data may be changed for the restart. KCHEK should be inserted equal to KMAX in the restart deck, although it may have been left at zero in the initial deck. We have used restarts to change yield strength or other model parameters which have not yet been used in the previous calculation.

Following the materials data the restart record is read into the usual arrays. At this time additional changes may be made by calling a user-written subroutine, EXTRAT. (NEXTRA is set to a positive number to trigger this call.) This subroutine can be constructed to modify any of the COMMON variables. For example, distorted cells in the ejecta region of a crater can be eliminated and fracture quantities can be inserted arbitrarily.

When the restarted calculations begin, the time step is set back to 10^{-12} sec as for any new calculation.

5.5 Matching Array Size to Problem Size

The number of coordinates in the J and K directions and the total number of variables available may be readily altered to match the size of a problem. The variables controlling these dimensions are all set in TROTT: JXX and KXX are the number of coordinates in the J and K directions, and JSIZE is the size of the COM array which contains the variables for each cell and coordinate. To change array sizes, these three variables are set in TROTT and the dimension statements for COM, XL, YL, MM, IZ and LVAR are set appropriately. No changes are required in the subroutines unless JXX exceeds 100: then the XDTEMP family of arrays are redimensioned in SWEEPT.

6. PRINTED OUTPUT

Several types of printed output are provided during and at the conclusion of a calculation. During the reading of input, the input lines are printed by LAYOUTT. Some material property subroutines read their own input and provide printout. At the conclusion of the input, a listing is given by LAYOUTT of the cell and coordinate layout. During the calculation SWEEPT makes several listings of the layout with current cell variables. At the end of the calculation, SCRIBET is called to produce a historical listing of all the variables requested. In addition, there are error messages and special printing from some material models. Samples of these listings are given here.

6.1 Input and Layout Listings

As the input is read by LAYOUTT, an echo print is made of each line. The input lines shown in Figure 9 (Section 5) are printed as in Figure 11. The listing in Figure 11 is the same as Figure 9 except for the addition of the date, gaps to separate material property groups, the sound speed listing (SP =) following material properties data, and the appended data "IN = 5 CAP." The latter note indicates that these data were read by the subroutine CAP1 from the input file TAPE 5.

Following the reading of all data and initialization of arrays by LAYOUTT, a listing (as in Figure 12) is made of some variables and array quantities that are used for each cell and coordinate. J and K are the Lagrangian coordinates, M is the material number, and LVAR shows the location in the COM array at which information for the coordinate begins. The Eulerian positions are X and Y. The area, density, and mass (A,D,Z) refer to the cell defined by the coordinates at (J,K), (J-1,K), (J,K-1), and (J-1, K-1). The initial yield strength, X and Y velocities, and the internal energy are also listed.

```
 OATE =   77/0T/09.
ND 28. CONC IMP, 92.35M/S, SANOIA ROO IMPACT SIMULATION
NSTAR   0 NPLUT 999 NDUMP 400 IMAX= 400 1PRIN  S0 JPRIN   0 NEXED 400         -0
IJ8UN   1 NBLUC  21 NMTRL   5 NJEO=   1          -0
TS=         .100E-02 IVTYPE =         -1 NVBLK =          1
CQSQ=       .400E+01 CLIN        .250E+00 TR1Q=       .200E-01
JEDT,K,J=     1321 2

IMPACTOR STEEL     RHOS=        .785E+01 CFP=  000 DPY=  001 NVAR=   2 NTRI=   1
EQSTC=      .159E+13  .517E+13  .736E+11  .169E+01  .250E+00  .517E+14-0.
YIELO=      .103E+11  .819E+12-0.

REBAR STEEL        RMDS         .78SE+01 CFP=  000 DPY=  001          -0         -0
EQSTC=      .159E+13  .S1TE+13  .T36E+11  .169E+01  .250E+00  .517E+14-0.
YIELD=      .103E+11  .819E+12-0.

CONCRETE           RHDS=        .28SE+01 CFP=  001 DPY = 000 NCON =  5
EQST =      .283E+12 0.         .100E+12  .200E+01  .250E+00 0.        -0.
RHD =       .222E+01 AMU =      .203E+12
AK =       T.000E+10 AK2 =    -5.S00E+01 MUP =     5.250E+10 MUP2 =     1.250E+02 IN= 5 CAP
MC=        1.040E+09-8.300E+08 2.T02E+09 2.500E+08 1.000E+00                       IN= 5 CAP
SCRIT =    2.000E+0T DAMG(M) = 1.000E-03                                           IN= 5 CAP
EVP =      0.          -1.200E-02-3.S00E-02-S.000E-02-2.230E-01                    IN= 5 CAP
NREG =             4 NPRCAP =           0 P1 =      -3.S00E+08 W2 =     1.250E+00 IN= 5 CAP
P2 =      -1.000E+09 OELP =     0.                                                 IN= 5 CAP
P2 =      -2.400E+09 DELP =     0.                                                 IN= 5 CAP
P2 =      -3.400E+09 OELP =     0.                                                 IN= 5 CAP
P2 =      -1.S33E+10 OELP =     0.                                                 IN= 5 CAP

REBAR              RMDS=        .250E+01 CFP=  100 DPY=  000 NVAR=  13
EQSTC=      .158E+12 0.         0.          .200E+01  .250E+00 0.        -0.
FS=         .650E-01 TMET=      0.          1MC=            3 1MS=             2

ALUMINUM           RMOS =       .270E+01 CFP=  000 DPY = 001 NVAR=   2
EQST =      .66TE+12  .100E+13  .122E+12  .204E+01  .250E+00 0.        -0.
YIELD =     .321E+10  .26TE+12-0.
SP= S.845E+05 S.84SE+05 4.994E+05 S.1T0E+0S 6.155E+05 0.
(1)     K=    20    68   X=        45.72000 13T.16000 137.16000  45.T2000 MAT =   1
        J=     1     2   Y=         0.00000   0.00000   1.2T000   1.27000
(2)     K=     1     3   X=         0.00000   3.81000   3.81000   0.00000 MAT =   3
        J=     1     4   Y=         0.00000   0.00000   3.81000   3.81000
(3)     K=     3     4   X=         3.81000   6.35000   6.35000   3.81000 MAT =   4
        J=     1     4   Y=         0.00000   0.00000   3.81000   3.81000
(4)     K=     4    1T   X=         6.35000  39.3T000  39.3T000   6.35000 MAT =   3
        J=     1     4   Y=         0.00000   0.00000   3.81000   3.81000
(S)     K=    17    18   X=        39.3T000  41.91000  41.91000  39.37000 MAT =   4
        J=     1     4   Y=         0.00000   0.00000   3.81000   3.81000
(6)     K=    18    20   X=        41.91000  45.72000  45.T2000  41.91000 MAT =   3
        J=     1     4   Y=         0.00000   0.00000   3.81000   3.81000
(T)     K=     1     3   X=         0.00000   3.81000   3.81000   0.00000 MAT =   3
        J=     4     8   Y=         3.81000   3.81000  11.43000  11.43000
(8)     K=     3     4   X=         3.81000   6.35000   6.3S000   3.81000 MAT =   4
        J=     4     8   Y=         3.81000   3.81000  11.43000  11.43000
(9)     K=     4    17   X=         6.35000  39.37000  39.3T000   6.35000 MAT =   3
        J=     4     8   Y=         3.81000   3.81000  11.43000  11.43000
(10)    K=    1T    18   X=        39.37000  41.91000  41.91000  39.37000 MAT =   4
        J=     4     8   Y=         3.81000   3.81000  11.43000  11.43000
(11)    K=    18    20   X=        41.91000  45.72000  4S.72000  41.91000 MAT =   3
        J=     4     8   Y=         3.81000   3.81000  11.43000  11.43000
(12)    K=     1     3   X=         0.00000   3.81000   3.81000   0.00000 MAT =   3
        J=     8    12   Y=        11.43000  11.43000  21.59000  21.59000
(13)    K=     3     4   X=         3.81000   6.35000   6.35000   3.81000 MAT =   4
        J=     8    12   Y=        11.43000  11.43000  21.S9000  21.59000
(14)    K=     4    17   X=         6.35000  39.3T000  39.3T000   6.35000 MAT =   3
        J=     8    12   Y=        11.43000  11.43000  21.S9000  21.59000
(15)    K=    17    18   X=        39.3T000  41.91000  41.91000  39.37000 MAT =   4
        J=     8    12   Y=        11.43000  11.43000  21.S9000  21.59000
(16)    K=    18    20   X=        41.91000  45.T2000  45.72000  41.91000 MAT =   3
        J=     8    12   Y=        11.43000  11.43000  21.S9000  21.59000
(17)    K=     1     3   X=         0.00000   3.81000   3.81000   0.00000 MAT =   3
        J=    12    19   Y=        21.59000  21.S9000  48.26000  48.26000
(18)    K=     3     4   X=         3.81000   6.35000   6.3S000   3.81000 MAT =   4
        J=    12    19   Y=        21.59000  21.S9000  48.26000  48.26000
(19)    K=     4    17   X=         6.35000  39.37000  39.3T000   6.35000 MAT =   3
        J=    12    19   Y=        21.59000  21.59000  48.26000  48.26000
(20)    K=    1T    18   X=        39.3T000  41.91000  41.91000  39.37000 MAT =   4
        J=    12    19   Y=        21.59000  21.59000  48.26000  48.26000
(21)    K=    18    20   X=        41.91000  45.72000  4S.T2000  41.91000 MAT =   3
        J=    12    19   Y=        21.S9000  21.59000  48.26000  48.26000
JU=            2                20 UZERO =  -923S.440
```

FIGURE 11   LISTING OF INPUT PROVIDED BY LAYOUTT FOR CONCRETE IMPACT CALCULATION

DATE = 77/07/09. NO 28, CONC IMP, 92.35M/S, SANDIA ROD IMPACT SIMULATION

J	K	M	LVAR	X	Y	A	D	Z	YIELD	XD	YD	E
1	1	0	1	0.000000	0.000000	0.000000	0.000000	0.000000	0.	0.	0.	0.
2	1	0	5	0.000000	1.270000	0.000000	0.000000	0.000000	0.	0.	0.	0.
3	1	0	9	0.000000	2.540000	0.000000	0.000000	0.000000	0.	0.	0.	0.
4	1	0	13	0.000000	3.810000	0.000000	0.000000	0.000000	0.	0.	0.	0.
5	1	0	17	0.000000	5.715000	0.000000	0.000000	0.000000	0.	0.	0.	0.
6	1	0	21	0.000000	7.620000	0.000000	0.000000	0.000000	0.	0.	0.	0.
7	1	0	25	0.000000	9.525000	0.000000	0.000000	0.000000	0.	0.	0.	0.
8	1	0	29	0.000000	11.430000	0.000000	0.000000	0.000000	0.	0.	0.	0.
9	1	0	33	0.000000	13.970000	0.000000	0.000000	0.000000	0.	0.	0.	0.
10	1	0	37	0.000000	16.510000	0.000000	0.000000	0.000000	0.	0.	0.	0.
11	1	0	41	0.000000	19.050000	0.000000	0.000000	0.000000	0.	0.	0.	0.
12	1	0	45	0.000000	21.590000	0.000000	0.000000	0.000000	0.	0.	0.	0.
13	1	0	49	0.000000	25.400000	0.000000	0.000000	0.000000	0.	0.	0.	0.
14	1	0	53	0.000000	29.210000	0.000000	0.000000	0.000000	0.	0.	0.	0.
15	1	0	57	0.000000	33.020000	0.000000	0.000000	0.000000	0.	0.	0.	0.
16	1	0	61	0.000000	36.830000	0.000000	0.000000	0.000000	0.	0.	0.	0.
17	1	0	65	0.000000	40.640000	0.000000	0.000000	0.000000	0.	0.	0.	0.
18	1	0	69	0.000000	44.450000	0.000000	0.000000	0.000000	0.	0.	0.	0.
19	1	0	73	0.000000	48.260000	0.000000	0.000000	0.000000	0.	0.	0.	0.
1	2	0	77	1.905000	0.000000	0.000000	0.000000	0.000000	0.	0.	0.	0.
2	2	3	81	1.905000	1.270000	2.419350	2.220000	10.231673	0.	0.	0.	0.
3	2	3	103	1.905000	2.540000	2.419350	2.220000	30.695019	0.	0.	0.	0.
4	2	3	125	1.905000	3.810000	2.419350	2.220000	51.158365	0.	0.	0.	0.
5	2	3	147	1.905000	5.715000	3.629025	2.220000	115.106322	0.	0.	0.	0.
6	2	3	169	1.905000	7.620000	3.629025	2.220000	161.148851	0.	0.	0.	0.
7	2	3	191	1.905000	9.525000	3.629025	2.220000	207.191380	0.	0.	0.	0.
8	2	3	213	1.905000	11.430000	3.629025	2.220000	253.233909	0.	0.	0.	0.
9	2	3	235	1.905000	13.970000	4.838700	2.220000	409.266923	0.	0.	0.	0.
10	2	3	257	1.905000	16.510000	4.838700	2.220000	491.120308	0.	0.	0.	0.
11	2	3	279	1.905000	19.050000	4.838700	2.220000	572.973693	0.	0.	0.	0.
12	2	3	301	1.905000	21.590000	4.838700	2.220000	654.827077	0.	0.	0.	0.
13	2	3	323	1.905000	25.400000	7.258050	2.220000	1135.715712	0.	0.	0.	0.
14	2	3	345	1.905000	29.210000	7.258050	2.220000	1319.885828	0.	0.	0.	0.
15	2	3	367	1.905000	33.020000	7.258050	2.220000	1504.055943	0.	0.	0.	0.
16	2	3	389	1.905000	36.830000	7.258050	2.220000	1688.226059	0.	0.	0.	0.
17	2	3	411	1.905000	40.640000	7.258050	2.220000	1872.396175	0.	0.	0.	0.
18	2	3	433	1.905000	44.450000	7.258050	2.220000	2056.566290	0.	0.	0.	0.
19	2	3	455	1.905000	48.260000	7.258050	2.220000	2240.736406	0.	0.	0.	0.
1	3	0	477	3.810000	0.000000	0.000000	0.000000	0.000000	0.	0.	0.	0.
2	3	3	481	3.810000	1.270000	2.419350	2.220000	10.231673	0.	0.	0.	0.
3	3	3	503	3.810000	2.540000	2.419350	2.220000	30.695019	0.	0.	0.	0.
4	3	3	525	3.810000	3.810000	2.419350	2.220000	51.158365	0.	0.	0.	0.
5	3	3	547	3.810000	5.715000	3.629025	2.220000	115.106322	0.	0.	0.	0.
6	3	3	569	3.810000	7.620000	3.629025	2.220000	161.148851	0.	0.	0.	0.
7	3	3	591	3.810000	9.525000	3.629025	2.220000	207.191380	0.	0.	0.	0.
8	3	3	613	3.810000	11.430000	3.629025	2.220000	253.233909	0.	0.	0.	0.
9	3	3	635	3.810000	13.970000	4.838700	2.220000	409.266923	0.	0.	0.	0.
10	3	3	657	3.810000	16.510000	4.838700	2.220000	491.120308	0.	0.	0.	0.
11	3	3	679	3.810000	19.050000	4.838700	2.220000	572.973693	0.	0.	0.	0.
12	3	3	701	3.810000	21.590000	4.838700	2.220000	654.827077	0.	0.	0.	0.
13	3	3	723	3.810000	25.400000	7.258050	2.220000	1135.715712	0.	0.	0.	0.
14	3	3	745	3.810000	29.210000	7.258050	2.220000	1319.885828	0.	0.	0.	0.
15	3	3	767	3.810000	33.020000	7.258050	2.220000	1504.055943	0.	0.	0.	0.
16	3	3	789	3.810000	36.830000	7.258050	2.220000	1688.226059	0.	0.	0.	0.
17	3	3	811	3.810000	40.640000	7.258050	2.220000	1872.396175	0.	0.	0.	0.
18	3	3	833	3.810000	44.450000	7.258050	2.220000	2056.566290	0.	0.	0.	0.
19	3	3	855	3.810000	48.260000	7.258050	2.220000	2240.736406	0.	0.	0.	0.
1	4	0	877	6.350000	0.000000	0.000000	0.000000	0.000000	0.	0.	0.	0.
2	4	4	881	6.350000	1.270000	3.225800	2.585950	15.891048	1.030E+10	0.	0.	0.

FIGURE 12 PORTION OF GRID LAYOUT WRITTEN BY LAYOUTT

6.2 Periodic Edits

At specified times in the calculation, listings are made of the major cell and coordinate variables at the time. A sample listing is given in Figure 13 for all the cells in K rows 15, 16, and 17 at cycle 200. The listing is requested by a nonzero valve of IPRINT. Then the listing occurs every IPRINT cycles. Locations are given in centimeters, stresses (positive in tension) and pressure (positive in compression) are given in megapascals $\doteq 10^7$ dynes/cm^2 = 0.01 kbar, internal energy is given in j/kg, density in g/cm^3, artificial viscous stress in MPa, sound speed squared in (km/sec)^2, and velocity in m/sec. The indicator H shows the path taken by the material for some material models; the meaning depends on the model.

For special material models, many variables may be used that are not listed in the usual edit in Figure 13. These extra variables beginning with the yield strength, COM(19), are given in the "extra edit," a sample of which is shown in Figure 14. The meaning of the individual variables must be traced through the call statement in SWEEPT to the material model subroutine as outlined in Appendix A. These extra edits are requested by a nonzero value of NEXED. The listing is provided by TROTT every NEXED cycles.

6.3 Historical Listings

Histories are provided for all COM array quantities and for many other variables through the specification of JEDT, JEDK and JEDJ as outlined in Section 5. A history is a list of values of the variable at each time step. During a calculation, the requested variables are stored at each cycle on tape 4. At the conclusion of the calculation, the subroutine SCRIBET is called by TROTT to read tape 4 and print the histories. A brief portion of a history is given in Figure 15. The listing consists of the cycle number N, time in microseconds, and the requested variables. For the standard variables the histories are identified by titles such as TZZ(12,5) for total stress in the Z direction in the cell at K=12, J=5. For extra variables the K,J values and the JEDT number are given to identify the history.

```
COLUMN K= 15. N= 200. TIME= .2147E-03. X= 34.2718. Y= 0.0000                                          XDNH, YDNH=    .397     0.000
 J     X        Y      TXXW      TYYW      TZZW      TXYW         P     E        D          Q     SPSQ     XDNH     YDNH  H
 2 34.2793  1.2767    8.3333    8.3333    8.3333    0.0000   -8.3333   .0 2.215329    0.0000  24.940    1.474    1.442  6
 3 34.2786  2.5418   -3.6127   -9.4080   13.1364    2.8420    -.0385   .0 2.219989    0.0000  24.940    -.083     .372  5
 4 34.2759  3.8115   -9.6442     .8482    4.4199   -3.6711     .9400   .0 2.220296     .5187  24.940     .086     .119  5
 5 34.2771  5.7197  -15.2432    4.6056    4.8856    5.5487    1.6682   .0 2.220520     .2491  24.940     .032     .002  5
 6 34.2792  7.6213   -7.1503   -3.8813    3.2135    6.7585    2.5449   .0 2.220785     .0611  24.940     .042    -.079  5
 7 34.2794  9.5287   -6.2271    1.0837    2.5358    3.2479     .7747   .0 2.220244     .0945  24.940    -.100     .048  5
 8 34.2819 11.4319   -4.7633   -2.5300    1.8025    5.9605    1.7719   .0 2.220551     .0583  24.940    -.057    -.158  5
 9 34.2824 13.9723   -2.1089   -1.3380    1.3597    2.5288     .6753   .0 2.220213     .0205  24.940    -.209    -.056  5
10 34.2841 16.5115   -2.5531   -1.2028     .9369    2.5566     .8997   .0 2.220283     .0400  24.940    -.202    -.120  5
11 34.2846 19.0518   -1.5432    -.4929     .8048    1.6171     .4074   .0 2.220129     .0030  24.940    -.300    -.124  5
12 34.2860 21.5915   -2.0033    -.4219     .6215    2.0073     .6012   .0 2.220189    0.0000  24.940    -.354    -.130  5
13 34.2873 25.4016   -1.2146    -.2443     .5553    1.8432     .2796   .0 2.220088     .0216  24.940    -.494    -.109  5
14 34.2891 29.2113    -.8829    -.5676     .4468    1.6571     .3029   .0 2.220096     .0316  24.940    -.379    -.072  5
15 34.2897 33.0211     .0764    -.8694     .3480     .7056     .1068   .0 2.220034     .0415  24.940    -.169    -.014  5
16 34.2901 36.8308     .2132   -1.0435     .1897     .1078     .1688   .0 2.220053     .0447  24.940     .007    -.021  5
17 34.2900 40.6405     .3732    -.9024     .1099    -.2272     .1313   .0 2.220042     .0085  24.940     .031    -.029  5
18 34.2900 44.4503     .1403    -.9055    -.0246    -.1296     .2633   .0 2.220083    0.0000  24.940     .034    -.019  5
19 34.2899 48.2600     .0947    -.9174    -.1321    -.0637     .3183   .0 2.220101    0.0000  24.940     .009    0.000  5
K= 15. F=-9.522E+08. M= 1.426E+10. YBAR= 2.413E+01
COLUMN K= 16. N= 200. TIME= .2147E-03. X= 36.8168. Y= 0.0000                                          XDNH, YDNH=   1.431     0.000
 J     X        Y      TXXW      TYYW      TZZW      TXYW         P     E        D          Q     SPSQ     XDNH     YDNH  H
 2 36.8176  1.2600    -.6924  -28.4696  -33.3772    1.4302   19.4490   .0 2.225104    1.3975  24.940    2.207   -2.229  5
 3 36.8082  2.5445    8.3333    8.3333    8.3333    0.0000   -8.3333   .0 2.216479    0.0000  24.940    -.265    -.453  6
 4 36.8125  3.8169  -38.4911    -.2202    6.3353   12.5414   10.5397   .0 2.221411     .2523  24.940    -.162    -.099  5
 5 36.8155  5.7170  -13.6261   -8.5217    8.4264    9.9387    4.5738   .0 2.221380    0.0000  24.940     .149     .132  5
 6 36.8160  7.6262  -12.2751    1.7773    5.2947    6.4736    1.4529   .0 2.220454     .2814  24.940    -.060     .023  5
 7 36.8203  9.5274   -6.6431   -5.9919    3.7790   11.1175    2.9400   .0 2.220903     .0120  24.940    -.048    -.084  5
 8 36.8206 11.4331   -1.5270   -4.0368    2.1825    3.8255     .9392   .0 2.220295     .1878  24.940    -.158     .043  5
 9 36.8230 13.9715   -2.0570   -3.0326    1.4507    3.6330    1.1929   .0 2.220373     .0200  24.940    -.088    -.077  5
10 36.8231 16.5117   -1.1302   -1.3318     .8869    1.3014     .5008   .0 2.220158     .0242  24.940    -.195    -.124  5
11 36.8247 19.0513   -2.4264    -.5862     .6129    1.9351     .7687   .0 2.220242     .0312  24.940    -.276    -.138  5
12 36.8254 21.5915   -1.3166    -.3894     .5784    1.7779     .3548   .0 2.220112     .0211  24.940    -.372    -.119  5
13 36.8274 25.4012   -1.3776    -.5266     .4371    2.0672     .4541   .0 2.220143     .0350  24.940    -.489    -.114  5
14 36.8288 29.2112    -.4151    -.4947     .3872    1.6206     .1298   .0 2.220041     .0444  24.940    -.448    -.066  5
15 36.8300 33.0208    -.0811    -.8416     .2712     .8264     .1722   .0 2.220055     .0450  24.940    -.166    -.055  5
16 36.8301 36.8306     .3966    -.8270     .1805    -.1496     .0364   .0 2.220012     .0469  24.940    -.007    -.064  5
17 36.8302 40.6404     .1779    -.7341     .0767    -.3208     .1326   .0 2.220042     .0272  24.940     .055    -.084  5
18 36.8300 44.4502     .2245    -.7216     .0020    -.2607     .1650   .0 2.220052    0.0000  24.940     .025    -.049  5
19 36.8300 48.2600     .1000    -.8349    -.1070    -.0518     .2806   .0 2.220089    0.0000  24.940     .034    0.000  5
K= 16. F=-1.253E+09. M= 2.139E+10. YBAR= 2.413E+01
COLUMN K= 17. N= 200. TIME= .2147E-03. X= 39.2968. Y= 0.0000                                          XDNH, YDNH=  -4.292     0.000
 J     X        Y      TXXW      TYYW      TZZW      TXYW         P     E        D          Q     SPSQ     XDNH     YDNH  H
 2 39.3352  1.2992   -3.6540   -3.6540   -3.6540    0.0000    0.0000   .2 2.217546    3.6540  24.940     .337    2.929 10
 3 39.3446  2.5483  -37.2866  -39.9267   11.4583   23.3181   20.0326   .2 2.226787    1.8858  24.940     .008     .594  7
 4 39.3454  3.8140  -30.5595  -18.4709   17.6822   13.1062   10.4494   .0 2.222412    0.0000  24.940     .184     .145  5
 5 39.3494  5.7264  -29.4889   -1.6825    3.3763   13.5904    8.9055   .0 2.221433     .3595  24.940    -.283    -.203  5
 6 39.3580  7.6235  -14.5553  -17.6205    5.3998   21.8249    8.9253   .0 2.221868    0.0000  24.940     .052     .193  5
 7 39.3590  9.5291     .5200  -11.2537    4.1151    6.7993    1.9428   .0 2.220603     .2635  24.940    -.147     .120  5
 8 39.3621 11.4315    -.1711   -6.2454    2.5349    5.3706    1.2354   .0 2.220387     .0585  24.940    -.132     .014  5
 9 39.3619 13.9717     .3254   -3.0192    1.1441     .9025     .3300   .0 2.220105     .1866  24.940    -.006    -.098  5
10 39.3634 16.5113   -2.3559    -.8094     .8050    1.5324     .7868   .0 2.220247    0.0000  24.940    -.168    -.099  5
11 39.3638 19.0514   -1.6451    -.7546     .4671    1.6724     .6135   .0 2.220193     .0307  24.940    -.263    -.114  5
12 39.3656 21.5910   -2.0185    -.8284     .2876    2.1053     .7969   .0 2.220251     .0561  24.940    -.373    -.153  5
13 39.3670 25.4011    -.8090    -.5126     .2939    1.8116     .2638   .0 2.220083     .0790  24.940    -.538    -.111  5
14 39.3692 29.2107    -.4419    -.6496     .2987    1.9104     .2383   .0 2.220075     .0259  24.940    -.462    -.063  5
15 39.3699 33.0206     .3984    -.7596     .2020     .6028    -.0117   .0 2.219996     .0648  24.940    -.182    -.070  5
16 39.3703 36.8304     .1595    -.5957     .1152    -.2462     .0557   .0 2.220018     .0513  24.940     .031    -.124  5
17 39.3701 40.6403     .2511    -.4290     .0788    -.5207     .0072   .0 2.220002     .0259  24.940     .034    -.132  5
18 39.3701 44.4502     .0733    -.4964     .0095    -.2783     .1379   .0 2.220044    0.0000  24.940     .039    -.087  5
19 39.3700 48.2600     .1216    -.6915    -.0919    -.1042     .2206   .0 2.220070    0.0000  24.940     .010    0.000  5
```

FIGURE 13 PORTION OF AN EDIT LISTING WRITTEN BY SWEEPT

```
 J          COLUMN K=    7
 2   0.            0.          1.947E-03   1.559E-01   2.807E+00
 3   0.            0.          1.857E-03   8.787E-02   2.813E+00
 4   0.            0.          1.477E-03   5.847E-02   2.830E+00
 5   0.            0.          1.379E-03   2.599E-02   2.854E+00
 6   0.            0.          1.501E-03   8.430E-04   2.866E+00
 7   0.            0.          9.313E-04   5.842E-04   2.893E+00
 8   0.            0.          8.310E-04   3.068E-04   2.907E+00
 9   0.            0.          1.020E-03   4.046E-04   2.918E+00
10   0.            0.          1.087E-03   1.309E-04   2.947E+00
11   0.            0.          7.917E-04   1.065E-04   2.972E+00
12   0.            0.          5.520E-04   3.686E-05   2.977E+00
13   0.            0.          5.214E-04   2.126E-05   2.982E+00
14   0.            0.          5.444E-04   2.334E-05   2.984E+00
15   0.            0.          5.374E-04   1.124E-05   2.988E+00
16   0.            0.          2.999E-04   1.049E-05   2.991E+00
17   0.            0.          2.906E-04   6.942E-06   2.995E+00
18   0.            0.          2.002E-04   6.108E-06   2.998E+00
19   0.            0.          1.704E-04   4.731E-06   3.001E+00
20   0.            0.          1.538E-04   3.766E-06   3.004E+00
21   0.            0.          1.078E-04   3.010E-06   3.007E+00
22   0.            0.          6.134E-05   2.363E-06   3.009E+00
23   0.            0.          3.296E-05   1.779E-06   3.012E+00
24   0.            0.          3.778E-05   1.245E-06   3.015E+00
25   0.            0.          3.618E-05   8.271E-07   3.017E+00
26   0.            0.          4.745E-05   4.896E-07   3.328E+00
 J          COLUMN K=    8
 2   0.            0.          1.913E-03   1.001E-01   3.335E+00
 3   0.            0.          2.120E-03   7.963E-02   3.333E+00
 4   0.            0.          1.639E-03   5.871E-02   3.349E+00
 5   0.            0.          1.979E-03   4.516E-02   3.348E+00
 6   0.            0.          1.963E-03   8.631E-03   3.378E+00
 7   0.            0.          1.084E-03   4.703E-04   3.407E+00
 8   0.            0.          2.410E-03   1.201E-02   3.408E+00
 9   0.            0.          1.316E-03   7.547E-05   3.433E+00
10   0.            0.          1.027E-03   7.510E-05   3.467E+00
11   0.            0.          1.498E-03   1.503E-02   3.478E+00
12   0.            0.          2.223E-03   1.573E-02   3.485E+00
13   0.            0.          2.182E-04   3.229E-05   3.488E+00
14   0.            0.          1.067E-04   3.198E-05   3.493E+00
15   0.            0.          2.687E-04   8.304E-06   3.496E+00
16   0.            0.          2.535E-04   5.873E-06   3.499E+00
17   0.            0.          2.196E-04   4.417E-06   3.502E+00
18   0.            0.          1.740E-04   2.898E-06   3.506E+00
19   0.            0.          8.185E-05   2.708E-06   3.508E+00
20   0.            0.          4.820E-05   2.101E-06   3.512E+00
21   0.            0.          4.780E-05   1.674E-06   3.514E+00
22   0.            0.          2.481E-05   1.156E-06   3.517E+00
23   0.            0.          1.558E-05   6.368E-07   3.520E+00
24   0.            0.          8.836E-06   2.498E-07   3.523E+00
25   0.            0.          3.652E-06   6.405E-08   3.525E+00
26   0.            0.          1.219E-06   4.826E-08   3.825E+00
 J          COLUMN K=    9
 2   1.030E+10  0.             3.102E-03   1.106E-02   4.636E-02   7.830E+00   2.211E+00   5.740E+04   5.383E+09   6.916E+09
  2.785E+08   0.           3.830E+00
 3   1.030E+10  0.             1.229E-03   6.299E-04   5.002E-02   7.824E+00   2.220E+00   3.214E+07   7.372E+09   6.159E+09
  6.705E+08   0.           3.842E+00
 4   1.030E+10  0.             1.270E-03   5.265E-04   4.993E-02   7.825E+00   2.220E+00  -1.809E+07   6.538E+09   6.736E+09
  1.390E+09   0.           3.849E+00
 5   1.030E+10  0.             9.100E-04   3.567E-04   4.985E-02   7.830E+00   2.220E+00   6.822E+07   4.159E+09   7.767E+09
  1.620E+09   0.           3.869E+00
 6   1.030E+10  0.             2.889E-03   1.163E-02   4.625E-02   7.829E+00   2.211E+00   1.042E+07   3.885E+09   8.653E+09
  1.251E+08   0.           3.871E+00
 7   1.030E+10  0.             5.495E-04   5.387E-05   4.966E-02   7.841E+00   2.219E+00   4.053E+07   6.402E+08   4.632E+09
  1.149E+09   0.           3.925E+00
 8   1.030E+10  0.             5.119E-04   3.901E-05   4.970E-02   7.842E+00   2.219E+00  -6.726E+07  -1.151E+09   5.783E+09
  2.670E+09   0.           3.976E+00
 9   1.030E+10  0.             3.383E-03   7.440E-02   2.828E-02   7.838E+00   2.164E+00  -6.485E+06   4.069E+09   3.134E+09
  2.873E+08   0.           3.963E+00
10   1.030E+10  0.             2.995E-03   8.423E-02   2.572E-02   7.840E+00   2.158E+00  -8.569E+05   6.578E+09  -3.747E+08
 -6.683E+07   0.           3.969E+00
11   1.030E+10  0.             2.592E-03   1.877E-02   4.425E-02   7.841E+00   2.206E+00  -5.094E+05   2.871E+09   2.692E+09
  4.319E+08   0.           3.990E+00
12   1.030E+10  0.             7.270E-04   2.340E-04   4.961E-02   7.841E+00   2.219E+00   1.345E+07   1.598E+09   3.631E+09
  6.038E+08   0.           3.991E+00
13   1.030E+10  0.             3.106E-03   4.236E-03   4.835E-02   7.842E+00   2.216E+00  -8.985E+06   1.703E+09   3.037E+09
  1.886E+08   0.           3.997E+00
14   1.030E+10  0.             2.434E-04   1.127E-05   4.972E-02   7.845E+00   2.219E+00   4.657E+06   6.897E+07   3.048E+09
  1.120E+09   0.           4.000E+00
15   1.030E+10  0.             7.638E-05   9.480E-06   4.972E-02   7.846E+00   2.219E+00   4.132E+07  -4.770E+08   2.718E+09
  7.071E+08   0.           4.004E+00
16   1.030E+10  0.             4.960E-05   3.151E-06   4.986E-02   7.847E+00   2.220E+00  -3.539E+07  -4.953E+08   2.538E+09
  4.124E+08   0.           4.007E+00
17   1.030E+10  0.             2.903E-05   1.817E-06   4.984E-02   7.848E+00   2.220E+00  -5.425E+06  -8.511E+08   2.285E+09
  4.860E+08   0.           4.010E+00
18   1.030E+10  0.             4.970E-05   8.772E-07   4.987E-02   7.848E+00   2.220E+00  -3.452E+07  -7.484E+08   2.114E+09
  3.636E+08   0.           4.013E+00
19   1.030E+10  0.             2.801E-05   4.787E-07   4.987E-02   7.848E+00   2.220E+00  -2.561E+07  -7.648E+08   1.919E+09
  3.647E+08   0.           4.017E+00
20   1.030E+10  0.             6.073E-07   1.569E-07   4.988E-02   7.848E+00   2.220E+00  -3.193E+07  -6.631E+08   1.788E+09
  3.025E+08   0.           4.019E+00
21   1.030E+10  0.             0.          0.          4.988E-02   7.848E+00   2.220E+00  -2.481E+07  -5.774E+08   1.640E+09
  2.673E+08   0.           4.022E+00
22   1.030E+10  0.             0.          0.          4.988E-02   7.848E+00   2.220E+00  -2.879E+07  -4.937E+08   1.544E+09
  2.404E+08   0.           4.025E+00
23   1.030E+10  0.             0.          0.          4.988E-02   7.848E+00   2.220E+00  -1.849E+07  -4.117E+08   1.432E+09
  1.997E+08   0.           4.028E+00
24   1.030E+10  0.             0.          0.          4.987E-02   7.848E+00   2.220E+00  -6.224E+06  -3.362E+08   1.360E+09
  1.604E+08   0.           4.030E+00
25   1.030E+10  0.             0.          0.          4.986E-02   7.848E+00   2.220E+00  -4.079E+06  -2.672E+08   1.274E+09
  8.587E+07   0.           4.033E+00
26   1.030E+10  0.             0.          0.          4.984E-02   7.848E+00   2.220E+00   4.575E+06  -1.923E+08   1.221E+09
  2.346E+07   0.           4.339E+00
```

FIGURE 14 PORTION OF AN EXTRA EDIT WRITTEN BY TROTT

DATE = 77/08/04. OSC-4 OIL SHALE(2ND 40 GAL/TON SHOT), NO DAMAGE, RUN C
NSCRIBE= 1, HISTORIES, TIME IN MUSEC, STRESS IN DYN/CM2, VELOCITY IN CM/SEC,DENSITY IN G/CM3

N	TIME	DT	DELTIM	TZZ(12, 5)	TZZ(12,13)	TYY(13, 2)	TYY(13, 6)	TYY(24, 2)	TZZ(24, 5)	TYY(24, 6)	TZZ(24,13)
51	1.720E+01	3.852E-07	1.076E+01	-6.858E+08	-8.702E+07	-2.182E+09	-1.662E+09	-2.149E+04	1.664E+06	-4.915E+06	-2.298E+03
52	1.755E+01	3.485E-07	4.703E+00	-6.227E+08	-8.869E+07	-2.101E+09	-1.629E+09	0.	1.547E+06	-5.017E+06	-3.421E+03
53	1.789E+01	3.455E-07	4.688E+00	-5.453E+08	-8.878E+07	-2.027E+09	-1.620E+09	0.	1.454E+06	-5.117E+06	-5.171E+03
54	1.824E+01	3.453E-07	4.751E+00	-4.618E+08	-8.714E+07	-1.959E+09	-1.628E+09	0.	1.373E+06	-5.217E+06	-7.964E+03
55	1.858E+01	3.450E-07	4.697E+00	-3.808E+08	-8.365E+07	-1.896E+09	-1.642E+09	0.	1.184E+06	-5.268E+06	-1.241E+04
56	1.896E+01	3.781E-07	4.655E+00	-3.034E+08	-7.774E+07	-1.832E+09	-1.647E+09	0.	7.384E+05	-5.243E+06	-2.010E+04
57	1.932E+01	3.626E-07	4.714E+00	-2.469E+08	-6.976E+07	-1.775E+09	-1.641E+09	0.	2.327E+05	-5.361E+06	-3.228E+04
58	1.967E+01	3.504E-07	4.742E+00	-2.116E+08	-6.013E+07	-1.725E+09	-1.624E+09	-2.235E+05	4.187E+04	-5.883E+06	-5.052E+04
59	2.002E+01	3.447E-07	4.759E+00	-1.951E+08	-4.900E+07	-1.680E+09	-1.593E+09	-1.096E+06	-2.542E+05	-6.719E+06	-7.761E+04
60	2.038E+01	3.579E-07	4.769E+00	-1.941E+08	-3.661E+07	-1.637E+09	-1.547E+09	-6.675E+05	-2.113E+06	-7.884E+06	-1.191E+05
61	2.073E+01	3.583E-07	4.682E+00	-2.093E+08	-2.409E+07	-1.597E+09	-1.492E+09	0.	-6.017E+06	-1.045E+07	-1.810E+05
62	2.109E+01	3.549E-07	4.693E+00	-2.241E+08	-1.033E+07	-1.560E+09	-1.434E+09	0.	-1.093E+07	-1.645E+07	-2.704E+05
63	2.144E+01	3.529E-07	4.709E+00	-2.325E+08	4.651E+06	-1.527E+09	-1.379E+09	-4.074E+07	-1.843E+07	-2.689E+07	-3.973E+05
64	2.180E+01	3.541E-07	4.705E+00	-2.312E+08	2.086E+07	-1.496E+09	-1.331E+09	-1.198E+08	-3.427E+07	-4.233E+07	-5.760E+05
65	2.219E+01	3.934E-07	4.794E+00	-2.214E+08	4.005E+07	-1.464E+09	-1.289E+09	-1.177E+08	-6.308E+07	-6.913E+07	-8.495E+05
66	2.252E+01	3.279E-07	4.774E+00	-2.051E+08	5.678E+07	-1.439E+09	-1.262E+09	-1.052E+08	-8.973E+07	-1.077E+08	-1.182E+06
67	2.286E+01	3.457E-07	4.717E+00	-1.803E+08	7.451E+07	-1.416E+09	-1.244E+09	-1.205E+08	-1.171E+08	-1.669E+08	-1.627E+06
68	2.320E+01	3.379E-07	4.735E+00	-1.515E+08	9.288E+07	-1.394E+09	-1.232E+09	-7.288E+09	-1.543E+08	-2.401E+08	-2.206E+06
69	2.359E+01	3.863E-07	4.803E+00	-1.176E+08	1.134E+08	-1.372E+09	-1.224E+09	-1.470E+10	-2.109E+08	-3.428E+08	-3.054E+06
70	2.394E+01	3.509E-07	4.704E+00	-9.016E+07	1.318E+08	-1.353E+09	-1.219E+09	-1.410E+10	-2.732E+08	-4.660E+08	-4.100E+06
71	2.429E+01	3.477E-07	4.704E+00	-6.909E+07	1.494E+08	-1.336E+09	-1.214E+09	-1.314E+10	-4.761E+08	-6.256E+08	-5.400E+06
72	2.463E+01	3.434E-07	4.715E+00	-5.576E+07	1.661E+08	-1.322E+09	-1.208E+09	-1.207E+10	-7.451E+08	-8.226E+08	-7.012E+06
73	2.497E+01	3.382E-07	4.669E+00	-5.009E+07	1.819E+08	-1.308E+09	-1.199E+09	-1.097E+10	-1.076E+09	-1.029E+09	-8.972E+06
74	2.530E+01	3.324E-07	4.744E+00	-5.371E+07	1.965E+08	-1.297E+09	-1.188E+09	-9.914E+09	-1.451E+09	-1.241E+09	-1.132E+07
75	2.563E+01	3.264E-07	4.759E+00	-6.142E+07	2.101E+08	-1.286E+09	-1.175E+09	-8.962E+09	-1.846E+09	-1.485E+09	-1.408E+07
76	2.600E+01	3.739E-07	1.102E+01	-7.126E+07	2.248E+08	-1.276E+09	-1.158E+09	-7.993E+09	-2.319E+09	-1.803E+09	-1.779E+07
77	2.636E+01	3.602E-07	4.748E+00	-7.880E+07	2.382E+08	-1.267E+09	-1.142E+09	-7.193E+09	-2.779E+09	-2.140E+09	-2.216E+07
78	2.672E+01	3.581E-07	4.763E+00	-8.239E+07	2.510E+08	-1.259E+09	-1.126E+09	-6.514E+09	-3.188E+09	-2.493E+09	-2.723E+07
79	2.708E+01	3.563E-07	4.792E+00	-8.161E+07	2.632E+08	-1.252E+09	-1.112E+09	-5.941E+09	-3.497E+09	-2.849E+09	-3.307E+07
80	2.745E+01	3.753E-07	4.800E+00	-7.662E+07	2.699E+08	-1.246E+09	-1.099E+09	-5.427E+09	-3.686E+09	-3.212E+09	-4.007E+07
81	2.780E+01	3.540E-07	4.804E+00	-7.011E+07	2.760E+08	-1.242E+09	-1.089E+09	-5.011E+09	-3.721E+09	-3.507E+09	-4.761E+07
82	2.815E+01	3.453E-07	4.807E+00	-6.392E+07	2.816E+08	-1.238E+09	-1.080E+09	-4.658E+09	-3.638E+09	-3.728E+09	-5.573E+07
83	2.854E+01	3.933E-07	4.836E+00	-5.775E+07	2.874E+08	-1.235E+09	-1.071E+09	-4.305E+09	-3.447E+09	-3.883E+09	-6.573E+07
84	2.892E+01	3.723E-07	4.786E+00	-5.486E+07	2.920E+08	-1.233E+09	-1.064E+09	-4.011E+09	-3.136E+09	-3.916E+09	-7.614E+07
85	2.931E+01	3.971E-07	4.860E+00	-5.829E+07	2.960E+08	-1.232E+09	-1.056E+09	-3.732E+09	-2.715E+09	-3.862E+09	-8.782E+07
86	2.970E+01	3.851E-07	4.842E+00	-6.723E+07	2.988E+08	-1.232E+09	-1.047E+09	-3.492E+09	-2.282E+09	-3.718E+09	-9.968E+07
87	3.008E+01	3.864E-07	4.849E+00	-7.966E+07	3.009E+08	-1.237E+09	-1.039E+09	-3.277E+09	-1.868E+09	-3.476E+09	-1.117E+08
88	3.045E+01	3.667E-07	4.827E+00	-9.450E+07	3.024E+08	-1.241E+09	-1.030E+09	-3.096E+09	-1.527E+09	-3.186E+09	-1.230E+08
89	3.084E+01	3.883E-07	4.835E+00	-1.137E+08	3.036E+08	-1.246E+09	-1.021E+09	-2.924E+09	-1.235E+09	-2.854E+09	-1.343E+08
90	3.123E+01	3.915E-07	4.858E+00	-1.352E+08	3.048E+08	-1.251E+09	-1.013E+09	-2.770E+09	-1.025E+09	-2.529E+09	-1.447E+08
91	3.161E+01	3.817E-07	4.833E+00	-1.577E+08	3.065E+08	-1.255E+09	-1.004E+09	-2.636E+09	-8.985E+08	-2.252E+09	-1.535E+08
92	3.197E+01	3.597E-07	4.833E+00	-1.805E+08	3.088E+08	-1.260E+09	-9.956E+08	-2.522E+09	-8.411E+08	-2.042E+09	-1.601E+08
93	3.236E+01	3.927E-07	4.916E+00	-2.086E+08	3.123E+08	-1.264E+09	-9.835E+08	-2.409E+09	-8.268E+08	-1.877E+09	-1.652E+08
94	3.271E+01	3.476E-07	4.885E+00	-2.360E+08	3.165E+08	-1.268E+09	-9.697E+08	-2.318E+09	-8.355E+08	-1.782E+09	-1.674E+08
95	3.309E+01	3.799E-07	4.858E+00	-2.683E+08	3.224E+08	-1.272E+09	-9.519E+08	-2.227E+09	-8.437E+08	-1.723E+09	-1.674E+08
96	3.344E+01	3.487E-07	4.894E+00	-3.006E+08	3.283E+08	-1.276E+09	-9.338E+08	-2.150E+09	-8.346E+08	-1.699E+09	-1.644E+08
97	3.384E+01	3.954E-07	4.901E+00	-3.415E+08	3.350E+08	-1.280E+09	-9.121E+08	-2.069E+09	-7.970E+08	-1.691E+09	-1.580E+08
98	3.423E+01	3.960E-07	4.898E+00	-3.873E+08	3.417E+08	-1.284E+09	-8.906E+08	-1.994E+09	-7.256E+08	-1.689E+09	-1.478E+08
99	3.457E+01	3.413E-07	4.831E+00	-4.298E+08	3.474E+08	-1.287E+09	-8.734E+08	-1.935E+09	-6.418E+08	-1.682E+09	-1.359E+08
100	3.493E+01	3.551E-07	4.887E+00	-4.758E+08	3.529E+08	-1.290E+09	-8.585E+08	-1.877E+09	-5.413E+08	-1.664E+09	-1.211E+08

FIGURE 15 PORTION OF A HISTORICAL LISTING WRITTEN BY SCRIBET

6.4 Miscellaneous Messages

Several error messages and a STOP message are provided by TROTT. Also several material model subroutines may print information about the current state of material in a cell.

The STOP message lists values of the stop criteria and the current values of variables that are compared with the criteria (see Figure 16). In the sample case the stop occurred as the result of an error that caused NSCRIB to be set to 1.

When excessive grid distortion occurs, cells may get so tangled that the cells areas become negative. When a negative area is computed, a message like that shown in Figure 16 is printed and NSCRIB is set to 1. Then at the completion of the time step, TROTT terminates the calculation with the usual historical listings.

STOP MESSAGE

```
STOP CRITERIA - IMAX = 375    TS = 6.000E-05  DT LESS THAN 1.E-12  NSCRIB = 1    CALTIM = 3.605E+02 SECONDS
  CURRENT VALUES - N = 258  TYME = 4.742E-05  DT      =  9.969E-08  NSCRIB = 1
```

ERROR MESSAGES

```
POINTS 234  K,J= 17  3 A124,A234= 1.151E+00-2.281E-01 XNW,XTEMP(J),XTEMP(J-1)= 1.732E+01 1.628E+01 1.818E+01
XKMJM,YNW,YTEMP(J)= 1.641E+01 4.996E+00 3.622E+00 YTEMP(J-1),YKMJM= 5.020E+00 3.841E+00
POINTS 234  K,J= 17  4 A124,A234= 6.104E-01-1.241E-01 XNW,XTEMP(J),XTEMP(J-1)= 1.697E+01 1.590E+01 1.628E+01
XKMJM,YNW,YTEMP(J)= 1.641E+01 4.673E+00 3.935E+00 YTEMP(J-1),YKMJM= 3.622E+00 3.841E+00
POINTS 234  K,J= 17  5 A124,A234= 1.152E-01-1.408E-02 XNW,XTEMP(J),XTEMP(J-1)= 1.676E+01 1.581E+01 1.590E+01
XKMJM,YNW,YTEMP(J)= 1.641E+01 4.776E+00 3.980E+00 YTEMP(J-1),YKMJM= 3.935E+00 3.841E+00
```

FIGURE 16 MISCELLANEOUS MESSAGES FROM THE TROTT PROGRAM

Appendix A

INSERTION PROCEDURE FOR MATERIAL MODELS

As new material models are generated, they can be added to TROTT for performing wave propagation calculations. The appendix describes the procedure for inserting material model subroutines and provides a sample case.

A wave propagation code normally has four main categories of operations: reading the input data, initializing a finite difference grid, performing calculations for each time increment at each grid point, and printing the computed information. A material model subroutine may be involved in all or some of these operations. Call statements must be provided in TROTT at appropriate locations to accomplish these tasks. Also the new subroutine should be provided with separate sections for each operation and an indicator to show which operation to perform. For example, in SHEAR2 the formal parameter NCALL indicates the operation required, as follows:

NCALL = 0 Initialize the routine and read data for one material
1 Read data for one material
2 Calculate stresses and damage
3 Calculate stresses and damage, and print results
4 Print results only.

The calls for NCALL = 0 and 1 are in LAYOUTT. There, NCALL is LSHB, a parameter that is initially zero. After the first call, LSHB is set to 1. For NCALL = 2 and 3, the call statement is in SWEEPT. Other calling strategies are also possible. For example, BFRACT is initialized on the first call from SWEEPT; there are no other calls. EXPLODE is called from LAYOUTT to read data and then called for each cell during the

layout to initialize array variables. During propagation calculation, EXPLODE is also called by SWEEPT.

At the point of insertion of the call statement, four elements are provided.

(1) The appropriate branching statements are needed to switch to the new model when it is required. For SHEAR2, it was decided to treat the model as a fracture routine and designate it by NFR(M) = 3. Then the available branching statements in LAYOUTT and SWEEPT were amplified to include one more branch.

(2) Variables must be initialized, calibrated, or given sign changes just preceding the call statement.

(3) The call statement is provided.

(4) Some variables may need to be reset following the calculations in the routine. Then a jump is provided to the appropriate section of SWEEPT or LAYOUTT to continue the calculation.

Items (2), (3), and (4) are discussed further below following introduction of a call statement.

A sample call statement for SHEAR2 is listed here as it appears in SWEEPT (the same call can be used in LAYOUTT).

```
CALL SHEAR2 (NCALL, IN, MAT, K, J, IH(LM), SXXW, SYYW, TXYW,
PW, COM(LM+24), DW, D(LM), DT, EW, E(LM), COM(LM+21), EMELT,
COM(LM+22), EXXH, EYYH, EXYH, F, YY(LM) COM(LM+23), TH(LM),
-ALFA, ESC, COM(LM+25))
```

Because SHEAR2 represents a fairly complex case, this call statement will be discussed in detail.

The initialization of NCALL for use in LAYOUTT was described above. For SWEEPT, NCALL (LS is the name used in SWEEPT) is initialized just before the call statement. NCALL is set to 2 normally, but it is set to 3 on cycles when an edit listing will occur. The parameter IN is the file containing input data. Normally IN is 5. MAT is the material number. The coordinate numbers J and K indicate the cell being treated; they are used for printout only. The deviator stress components SXXW,

SYYW, TXYW are positive in tension, whereas the pressure PW is positive in compression. If necessary, sign and magnitude changes can be made in the stresses just preceding the call statement. The current and previous density and energy values are DW, D(LM), EW, and E(LM). The strain increments EXXH, EYYH, EXYH are also positive in tension. For SHEAR2 the standard equation-of-state constants are contained in the ESC array as follows:

ESC(MAT,1)	=	initial density, g/cm^3
ESC(MAT,2)	=	bulk modulus, dyn/cm^2
ESC(MAT,3) ESC(MAT,4)	=	D, S; the second and third coefficients of the Hugoniot series expansion for pressure, dyn/cm^2
ESC(MAT,5)	=	shear modulus, dyn/cm^2
ESC(MAT,9)	=	Grüneisen's ratio.

All the cell quantities are stored in a single large array called COM. The particular locations assigned to cell J,K begin at LM = LVAR(K,J). IH(LM) = indicator, D(LM), E(LM), YY(LM) = yield strength, and TH(LM) = rotation are all in this array. Quantities COM(LM+24), etc., are also in the array. This allocation of space in the COM array is discussed further in Appendix B.

Following insertion of a new material model, it is a good plan to run a simple problem with frequent edits to determine whether the routine is performing satisfactorily.

Appendix B

COORDINATE AND CELL VARIABLES

All the cell and coordinate variables are stored in a single large one-dimensional array called COM( ). The array locations that pertain to each cell or coordinate are identified by an auxiliary array, LVAR(K,J). Extra array locations may be provided for a cell through the use of the indicator NVAR(M). Quadrilateral cells may be divided into triangular cells with the use of NTRI(M). Operations with these four variables are described below.

The standard 17 variables associated with cells and coordinates are listed in Table B.1. These variables are equivalenced to the COM array for convenience in identifying them. For example,

```
X(L)  = COM(L)
Y(L)  = COM(L + 1)
XD(L) = COM(L + 2)
Z(L)  = COM(L + 6)
P(L)  = COM(L + 15)
```

Thus all the variables associated with a particular cell or coordinate are stored one after the other in the COM array. The starting location, L, for the set is given by the LVAR array. Thus for the point K, J, the starting point is L = LVAR(K, J). To find a value such as $P_{K,J}$, two steps are required:

$$L = LVAR(K, J)$$

$$P_{K,J} = P(L)$$

In the layout, cells are numbered according to the highest number coordinates around the cell. That is, for cell K, J the coordinates are (K-1, J-1), (K-1, J), K, J-1), and K, J). Therefore, in a normal layout

Table B.1

STANDARD VARIABLES FOR EACH COORDINATE AND CELL

No.	Name	Definition
1	X	Eulerian position in the x direction, cm
2	Y	Eulerian position in the y direction, cm
3	XD	Particle velocity in the x direction, cm/sec
4	YD	Particle velocity in the y direction, cm/sec
5	M	Material number (normally unused)
6	A	Cell area in the xy plane, cm^2
7	Z	Cell mass in planar problems, g/cm; $1.5/\pi$ times cell mass in axisymmetric problems, g
8	D	Cell density, g/cm^3
9	SXX	Deviator stress in x direction, dyn/cm^2
10	SYY	Deviator stress in y direction
11	SZZ	Deviator stress in z direction, dyn/cm^2
12	TXY	Shear stress on xy plane, dyn/cm^2
13	TXX	Total stress in x direction, dyn/cm^2
14	TYY	Total stress in y direction, dyn/cm^2
15	TZZ	Total stress in z direction, dyn/cm^2
16	P	Pressure, dyn/cm^2
17	E	Internal energy, erg/g

there are some coordinates, such as (1,1) that are not associated with a cell. For these only four variables (X, Y, XD, and YD) are needed. For the usual cell and coordinate combination, 17 variables are allocated. For material models that require more variables, an input variable NVAR is set to the additional number required. In summary, the number of variables allocated are:

Coordinate only	4 variables
Standard cell and coordinate	17 variables
Special cell and coordinate	17 + NVAR(M)

The LVAR array is initialized in such a way that the COM array is just filled, with no gaps remaining between variable sets for each cell. The NVAR(M) input variable is required for all but simple elastic materials. Yield and explosive models require two extra variables. The numbers required for some special models are listed in Table B.2.

Triangular cells may be used instead of quadrilateral cells for any material. The triangular cells are stiffer than quadrilateral cells and hence tend to resist distortion in regions of high shear flow. Because they resist shear distortion partially by a density change, the pressures in such cells often vary wildly. Hence it is advisable to use the triangular cells only where absolutely necessary and not to use a pressure-sensitive material model for the cell material.

The triangular cell feature is initiated by setting NTRI = 1 for the material. Then each standard quadrilateral cell K, J is divided into two triangular cells with coordinates

(K, J), (K, J-1), (K-1, J)

and (K, J-1), (K-1, J), (K-1, J-1).

A larger storage array is required for this special double cell. There are four (coordinates), 13 (cell), 12 (second cell), plus 2 x NVAR variables for a quadrilateral cell treated as two triangular cells.

Table B.2

EXTRA VARIABLES REQUIRED FOR SPECIAL MODELS

Model	NVAR
CAP1	5
REBAR	12
SHEAR2	Variable, minimum 13
BFRACT3	23
EXPLODE	2
DFRACT	6
DFRACTS	5

To obtain historical information from triangular cells, the storage process must be traced to locate the variable of interest. For example, the request for pressure in both triangles at cell K=10, J=20 would read

161020 L1020

where 16 is the number for pressure in Table B.1 and L = 17 + NVAR +16 - 5, in which 17 is the standard number for the coordinate and the first triangular cell, NVAR is for the extra variables in the first cell, 16 - 5 is for the location of the pressure variable for the second triangular cell. This request for historical input is also described in Section 5 and Table 2.

For large or oddly shaped problems, it may be necessary to redimension some of the arrays. These arrays are COM, XL, YL, MM, IZ, and LVAR in TROTT; XDTEMP and YDTEMP in SWEEPT; and the array size constants JSIZE, JXX, and KXX in TROTT. JXX and KXX must be greater than or equal to the number of coordinates in the J and K directions, and must equal the dimension of the arrays XL, YL, MM, IZ, and LVAR. JSIZE is the length of the COM array. XDTEMP and YDTEMP must be dimensioned to be at least as long as JXX.

Appendix C

SAMPLE INPUT DECKS

This appendix provides some sample input decks and supplements the input description in Section 5. Several data decks are provided to illustrate the main features of TROTT and the range of problems that can be treated. General guidelines for constructing the decks are listed below:

- The data fields are usually in multiples of 5 or 10 characters.
- The first column is reserved for indicators and is normally blank.
- Columns 2 through 10 are usually labels only.
- Any number of decks can be run, one following the other with no separators between decks.

Problems of planar and cylindrical geometry can be run by appropriate use of the indicator IJBUND (see Table 1 in Section 5). The activation is usually prescribed either by velocities or a detonation. Sample problems with these geometries and activation mechanisms are provided in the following figures.

Figure C.1 contains an input deck for a one-dimensional simulation of a plate impact problem in lexan. Only one cell in the J direction is used. The second lexan material is treated by the NAG brittle fracture model.

A two-dimensional simulation of an impact of a rod onto an oblique plate is initialized by the data deck in Figure C.2. The rod is treated as a plate and the target is simply a rigid boundary at 45°. Triangular cells are used for the row of cells along the impact plane.

```
DUPLICATE PUFF RUN 1033-51 IMPACT IN LEXAN FOR D. SHOCKEY
NSTAR    0 NPLOT 999 NDUMP 999 IMAX= 100 IPRIN  10 JPRIN    1
IJBUND -1 NBLOCK  3 NMTRLS  3 NJED=  16
TS =       15.00E-06 IVTYPE =          1 NVBLK =          0
COSQ =           4.0 CLIN =          0.1 TRIQ =          0.
KSLIDE  0 JSLIDE  0
JPR =          96  100
JEDT,K,J=  -510202  -510402  -510602  -510802  -511402  -511602  -511802
           -512002  -512102  -512202  -512302  -512402  -512502  -512602
           -512802  -513002

LEXAN                 RHOS =          1.20 CFP=  000 DPY=  000 NVAR =  0 NTRI =  0
EQST =     4.720E+10-1.330E+11 1.000E+11       1.30         .25 3.500E+12

LEXAN                 RHOS =          1.20 CFP=  060 DPY=  000 NVAR =  2 NTRI =  0
EQST =     4.720E+10-1.330E+11 1.000E+11       1.30         .25 3.500E+12
TSR =     -1.000E+07

LEXAN FRACTURE        RHOS =           1.2 CFP = 020 DPY=  001 NVAR = 26 NTRI =  0
EQST =     4.720E+10-1.330E+11 1.000E+11        1.3         .25 3.500E+12
BFR =     -5.000E-04 3.600E+07        .002 3.500E+10-1.670E+09-1.410E+08        .02
BFR 2     -1.670E+09        0.         .25        1.0        .20        4.0
YIELD =    1.000E+11 2.000E+10

K  =            1    10 X =            0.      .2745      .2745        0. MAT =   1
J  =            1     2 Y =            0.         0.        .03       .03
K  =           10    11 X =         .2745       .305       .305     .2745 MAT =   2
J  =            1     2 Y =            0.         0.        .03       .03
K  =           11    33 X =          .305       .963       .963      .305 MAT=    3
J  =            1     2 Y =            0.         0.        .03       .03
JU =                 11 KU =           11 UZERO =    1.522E+04
7/8/9
```

FIGURE C.1 SIMULATION OF A ONE-DIMENSIONAL PLANAR IMPACT OF LEXAN PLATES UNDERGOING BRITTLE FRACTURE

```
OBLIQUE PLATE IMPACT WITH BFRACT, 45 DEG., UZERO=1.E+05 CM/SEC
NSTAR    0 NPLOT 999 NDUMP 999 IMAX     0 IPRIN 200 JPRIN    1          NOBLQ    1
ANGLE =         45.
IJBUND -3 NBLOCK   4 NMTRLS   3 NJED = 13
TS =        1.000E-04 IVTYPE =           -1 NVBLK =           1
CQSQ =      .4000E+01 CLIN =     .1000E+00 TRIQ =     .1000E+00
KSLIDE  0 JSLIDE   0
JP1,JP2 =     1     5
JEDT,K,J=    -5110 2   -5110 6   -5115 2   -5115 6   -5120 2   -5120 6   -5125 2
             -5125 6   -5130 2   -5130 3   -5130 4   -5130 5   -5130 6

ARMCO FRACTURE          RHOS =     .7850E+01 CFP=  020 DPY = 001 NVAR = 23
EQST =      .1590E+13  .517E+13  .736E+11  .169E+01  .250E+00  .517E+14
BFR 1 =    -.550E-03 -.100E+09  .500E-04  .400E+13 -.300E+10-.5270E+10
BFR 2  =   -.300E+10        0.  .250E+00  .500E+00  .400E+00  .300E+01
YIELD =     .550E+10  .819E+12
ARMCO IRON              RHOS =     .7850E+01 CFP=  000 DPY = 001 NVAR =  2 NTRI =   1
EQST =      .1590E+13  .517E+13  .736E+11  .169E+01  .250E+00  .517E+14
YIELD =     .550E+10  .819E+12

ARMCO IRON              RHOS =     .7850E+01 CFP=  000 DPY = 001 NVAR =  2
EQST =      .1590E+15  .517E+13  .736E+11  .169E+01  .250E+00  .517E+14
YIELD =     .550E+10 2.380E+14

K =              1    29  X =          0.        6.72      6.72      0.   MAT =   1
J =              1     6  Y =          0.          0.      1.20      1.2
      K =       29    30 X =          6.72   6.86      7.1           6.72 MAT =   2
    J =          1     2     Y =       0.    0.                  .24    .24
      K =       29    30 X =          6.72   7.1       7.1           6.72 MAT =   2
      J =        2     5     Y =       .24        .24        .96       .96
      K =       29    30 X =          6.72    7.1      6.86          6.72 MAT =   2
      J =        5     6     Y =       .96        .96        1.2       1.2
JU =                   0 KU =                0 UZERO =   1.000E+05
7/8/9
```

FIGURE C.2 IMPACT OF AN ARMCO IRON PLATE ONTO A RIGID WALL AT 45°, WITH TRIANGULAR CELLS IN THE REGION OF IMPACT

A planar problem with just two cells is illustrated in Figure C.3. The calculation was made to examine coefficients to use for the triangular artificial viscosity. The velocity initialization shows the method for laying out velocities by quadrilateral blocks.

Figures C.4, C.5, and C.6 contain decks for impacts of cylinders along their common axes. Figure C.4 simulates a simple impact of two cylinders to test radial motion of the free cylindrical walls.

Radial motions are also of interest in the impact prescribed by the deck in Figure C.5. The simulation includes a PMMA flyer plate on the front of an aluminum projectile described in geometric detail. The target is a disk of zinc sulfide inside an aluminum guard ring; both disks are encased in lexan. The lexan housing is also inside a separable lexan guard ring. The special spall features of materials 2 and 4 (CFP = 050 or 060) permit spallation along radial and circumferential surfaces.

Impact of a steel cylinder (with a 2.5-inch diameter aluminum projectile) onto a reinforced concrete target is simulated with the data deck in Figure C.6. The concrete is treated by a cap plasticity model and the reinforcing steel layers by a composite model.

Explosions activate the problems in Figures C.7, C.8, and C.9. The deck in Figure C.7 simulates a detonation running along the axis of a small PETN charge in a cylinder of oil shale. The calculation was made to examine radial stresses at planes where stress gages had been located in the corresponding experiment.

Figure C.8 is the input deck for a contained fragmenting round experiment. The motion is caused by a running detonation in PETN down the axis of the fragmenting steel cylinder, which is being treated by the shear band model (CFP = 030). Radial motion of the round is presented by surrounding the round with cylinders of PMMA, steel, and lead, in that order. Problems with the large distortions at the outer ends of the fragmenting steel cylinder are avoided by making the outermost rows of cells triangular instead of quadrilateral.

```
HOURGLASSING SAMPLE TO TEST TRIQ EFFECTIVENESS
NSTAR    0 NPLOT 999 NDUMP 999 IMAX    50 IPRIN    1
IJBUND -3-NBLOCK   1 NMTRLS   1 NJED=    5
TS =        1.000E-04 IVTYPE =            2 NVBLK =           2
CQSQ =      4.E        CLIN =     0.1E      TRIQ =     0.03E0
KSLIDE  0 JSLIDE  0
JED =           3 2 1      3 2 2     -51 2 2     3 2 3     -51 2 3

IMPACTOR STEEL      RHOS=           7.85E  CFP=  000 DPY = 001 NVAR =  2
EQSTC=     1.5889E12  5.170E12  7.360E10     1.69E0     0.25E0 5.170E+13
YIELD=      1.222E10  8.188E11

 K =            1    2  X =       0.        1.        1.        0.        MAT =   1
  J =           1    3  Y =        0.       0.        2.        2.
K =             1    2  XDOT =  -10000.    10000.    10000.   -10000.
J =             1    3 YDOT =   0.          0.        0.        0.
K =             1    2 XDOT =    10000.   -10000.
J  =            2    2  YDOT =   0.          0.
7/8/9
```

FIGURE C-3 TEST OF THE DAMPING PROVIDED BY THE TRIANGLE ARTIFICIAL VISCOSITY TO COMBAT HOURGLASSING MOTIONS

```
CYLINDRICAL IMPACT FOR TESTING LATERAL MOTION
NSTAR    0 NPLOT 999 NDUMP 999 IMAX   100 IPRIN   10
IJBUND   2 NBLOCK   2 NMTRLS   1 NJED=   40
TS =       1.000E-04 IVTYP =            1 NVBLK =           0
CQSQ =     4.E        CLIN =    0.1E      TRIQ =     0.01
KSLIDE   0 JSLIDE   0
JEDT=K,J=     4 5 1     4 5 4     4 6 1     4 6 2   -46 6 2   -47 6 2   -48 6 2
            -49 6 2   -50 6 2   -51 6 2   -52 6 2   -53 6 2     9 6 2    10 6 2
             11 6 2    12 6 2    16 6 2   -46 6 4   -47 6 4   -48 6 4   -49 6 4
            -50 6 4   -51 6 4   -52 6 4   -53 6 4     9 6 4    10 6 4    11 6 4
             12 6 4    16 6 4     4 6 4   -53 7 2   -53 7 3   -53 7 4   -53 8 2
            -53 8 3   -53 8 4   -53 9 2   -53 9 3   -53 9 4

IMPACTOR STEEL      RHOS=          7.85E0 CFP=  000 DPY = 001 NVAR =  2
EQSTC=     1.5889E12  5.170E12  7.360E10     1.69E0     0.25E0  5.170E13
YIELD=      1.222E10  8.188E11

 K =         1     6   X =      0.        1.        1.        0.        MAT =   1
 J =         1     5   Y =      0.        0.        0.8       0.8
 K =         6    11   X =      1.0       2.0       2.0       1.0       MAT =   1
 J =         1     4   Y =      0.        0.        0.6       0.6
 JU =              4   KU =              6 UZERO =  1.000E+04
7/8/9
```

FIGURE C-4 IMPACT OF TWO STEEL CYLINDERS ALONG THEIR AXIS TO STUDY RADIAL INERTIA EFFECTS

```
ZINC SULFIDE /GUARD RING IMPACT FOR Y. GUPTA. 4928-4
NSTAR    0 NPLOT 999 NOUMP 999 IMAX= 100 IPRIN  10 JPRIN    0             NOBLQ    0
IJBUND   2 NBLOCK 30 NMTRLS   6 NJEO=  30
TS =       20.00E-06 IVTYPE =          1 NVBLK =           0
COSQ =            4. CLIN =          0.1 TRIQ =          0.1
KSLIOE   0 JSLIOE  0
JEOT,K,J=    -5115 2   -5215 2   -5315 2   -5118 2   -5218 2   -5318 2   -5118 5
             -5218 5   -5318 5   -5119 3   -5219 3   -5319 3   -5121 2   -5221 2
             -5321 2   -5121 5   -5221 5   -5321 5   -5123 3   -5223 3   -5323 3
             -5124 4   -5224 4   -5324 4   -5125 2   -5225 2   -5325 2   -5128 2
             -5228 2   -5328 2

PMMA-8KB (BARKER)    RHOS =          1.184 CFP=  000 OPY = 001 NVAR =  2 NTRI =  0
EQST =     5.750E+10 4.050E+11 1.000E+10          1.          .25 3.640E+11
YIELO =    2.000E+09 2.280E+10 2.850E+09

PMMA-8KB (BARKER)    RHOS =          1.184 CFP=  050 OPY=  001 NVAR =  2 NTRI =  0
EQST =     5.750E+10 4.050E+11 1.000E+10          1.          .25 3.640E+11
TSR =      1.000E+07
YIELO =    2.000E+09 2.280E+10 2.850E+09

LEXAN                RHOS =    1.200     CFP=  000 OPY=  001 NVAR =  2 NTRI =  0
EQST =     4.750E+10-1.330E+11 1.000E+11       1.300          .25 3.500E+12
YIELO =    2.000E+09 1.000E+10

LEXAN                RHOS =    1.200     CFP=  060 DPY=  001 NVAR =  2 NTRI =  0
EQST =     4.750E+10-1.330E+11 1.000E+11       1.300          .25 3.500E+12
TSR =      1.000E+07
YIELO =    2.000E+09 1.000E+10

AL6061-T6            RHOS =          2.707 CFP = 000 OPY = 001 NVAR =  2 NTRI =  0
EQST =     6.670E+11 1.000E+12 1.220E+11        2.04          .25          0.
YIELO =    3.210E+09 2.670E+11 3.790E+10

ZNS                  RHOS =          4.079 CFP=  000 OPY = 001 NVAR =  2 NTRI =  0
EQST =     .7190E+12        0. 2.037E+11          2.          .25          0.
YIELD =    10.00E+09 .3180E+12

K =          1    5 X =             0.     10.16      10.16          0. MAT =    5
J =         13   14 Y =           3.81      3.81       5.08        5.08
K =          5    9 X =          10.16     15.24      15.24       10.16 MAT =    5
J =         13   14 Y =           3.81      3.81       5.08        5.08
K =          9   11 X =          15.24  16.66875   16.66875       15.24 MAT =    5
J =          1   13 Y =          0.           0.    4.60375        3.81
K =          9   11 X =          15.24  16.66875   16.66875       15.24 MAT =    5
J =         13   14 Y =           3.81   4.60375       5.08        5.08
K =         11   12 X =       16.66875   17.6022      17.27    16.66875 MAT =    5
J =         13   14 Y =        4.60375   4.60375       5.08        5.08
K =         12   13 X =        17.6022   17.6911    17.6911     17.6022 MAT =    1
J =          1   12 Y =             0.        0.       3.89        3.89
K =         12   13 X =        17.6022   17.6911    17.6022     17.6022 MAT =    1
J =         12   13 Y =           3.89      3.89    4.92125     4.60375
K =         12   13 X =        17.6022   17.6022    17.6022       17.27 MAT =    5
J =         13   14 Y =        4.60375   4.92125       5.08        5.08
K =         13   14 X =        17.6911     17.78      17.78     17.6911 MAT =    2
J =          1   12 Y =             0.        0.       3.89        3.89
K =         13   14 X =        17.6911     17.78      17.78     17.6022 MAT =    2
J =         12   13 Y =           3.89      3.89    4.92125     4.92125
K =         13   14 X =        17.6022     17.78      17.78     17.8022 MAT =    5
J =         13   14 Y =        4.92125   4.92125       5.08        5.08
K =         14   17 X =          17.78   18.0848    18.0848       17.78 MAT =    3
J =          1    5 Y =             0.        0.     1.5875      1.5875
K =         14   17 X =          17.78   18.0848    18.0848       17.78 MAT =    3
J =          5    9 Y =         1.5875    1.5875     2.8575      2.8575
K =         14   17 X =          17.78   18.0848    18.0848       17.78 MAT =    3
J =          9   12 Y =         2.8575    2.8575     3.9113        3.89
K =         14   17 X =          17.78   18.0848    18.0848       17.78 MAT =    4
J =         12   13 Y =           3.89    3.9113    4.92125     4.92125
K =         14   17 X =          17.78   18.0848    18.0848       17.78 MAT =    3
J =         13   14 Y =        4.92125   4.92125       5.08        5.08
K =         14   17 X =          17.78   18.0848    18.0848       17.78 MAT =    3
J =         14   17 Y =           5.08      5.08       8.89        8.89
K =         17   25 X =        18.0848    19.333     19.333     18.0848 MAT =    6
J =          1    5 Y =             0.        0.     1.5875      1.5875
K =         17   25 X =        18.0848    19.333     19.333     18.0848 MAT =    5
J =          5    9 Y =         1.5875    1.5875     2.8575      2.8575
K =         17   25 X =        18.0848    19.333     19.333     18.0848 MAT =    3
J =          9   12 Y =         2.8575    2.8575     3.9986      3.9113
K =         17   25 X =        18.0848    19.333     19.333     18.0848 MAT =    4
J =         12   13 Y =         3.9113    3.9986    4.92125     4.92125
K =         17   25 X =        18.0848    19.333     19.333     18.0848 MAT =    3
J =         13   14 Y =        4.92125   4.92125       5.08        5.08
K =         17   25 X =        18.0848    19.333     19.333     18.0848 MAT =    3
J =         14   17 Y =           5.08      5.08       8.89        8.89
K =         25   33 X =      19.333      21.6093    21.6093      19.333 MAT =    3
J =          1    5 Y =          0.           0.     1.5875      1.5875
K =         25   33 X =      19.333      21.6093    21.6093      19.333 MAT =    3
J =          5    9 Y =         1.5875    1.5875     2.8575      2.8575
K =         25   33 X =      19.333      21.6093    21.6093      19.333 MAT =    3
J =          9   12 Y =         2.8575    2.8575     4.1578      3.9986
K =         25   33 X =      19.333      21.6093    21.6093      19.333 MAT =    4
J =         12   13 Y =         3.9986    4.1578    4.92125     4.92125
K =         25   33 X =      19.333      21.6093    21.6093      19.333 MAT =    3
J =         13   14 Y =        4.92125   4.92125       5.08        5.08
K =         25   33 X =      19.333      21.6093    21.6093      19.333 MAT =    3
J =         14   17 Y =           5.08      5.08       8.89        8.89
K =         33   36 X =        21.6093   26.6893    26.6893     21.6093 MAT =    5
J =         14   17 Y =           5.08      5.08       8.89        8.89
JU =             14 KU =             14 UZERO =   1.901E+03
7/8/9
```

FIGURE C-5 IMPACT OF A PMMA FLYER PLATE ONTO A ZINC SULFIDE DISK WITH AN ALUMINUM GUARD RING AND ENCAPSULATED IN LEXAN

```
NO 16, CONC IMP, 22.34M/S, FULL PROJ., MOMENTUM CHECK
NSTAR    0 NPLOT 999 NDUMP 999 IMAX= 600 IPRIN 100 JPRIN    4 NEXED 600
IJBUND   2 NBLOCK 16 NMTRLS  5 NJED=   8
TS=        2.000E-04 IVTYPE =          -1 NVBLK =            1
CQSQ=      4.000E+00 CLIN       2.500E-01 TRIQ=       0.020E+00
KSLIDE  0 JSLIDE  0
JPR =        200   202   300   302   400   402   500   502
JEDT,K,J=      1317 2     1317 3     1317 4     1323 2     1323 3     1323 4     1327 8
               1330 8

IMPACTOR STEEL       RHOS=            7.85E0 CFP=  000 DPY = 001 NVAR =  2
EQSTC=     1.5889E12  5.170E12  7.360E10     1.69E0     0.25E0   5.170E13
YIELD=     1.030E+10  8.188E11

REBAR STEEL          RHOS=            7.85E0 CFP=  000 DPY=  001 NVAR=   2
EQSTC=     1.5889E12  5.170E12  7.360E10     1.69E0     0.25E0   5.170E13
YIELD=      1.030E10  8.188E11

CONCRETE             RHOS =       2.85 E0    CFP = 004 DPY = 000 NVAR =  5
EQST =     2.830E+11 0.         1.000E+11 2.000E+00 .25        0.
RHO =      2.22E0     AMU =     2.033E+11
AK =       7.000E+10 AK2 =     -.5500E+02 MUP =      5.250E+10 MUP2 =     .1250E+03
MC =       1.040E+09-8.300E+08 2.702E+09 2.500E+08 1.000E0
SCRIT =    2.000E+07 DAMG(M) = 1.000E-03
EVP =             0.-1.200E-02-3.500E-02-5.000E-02-2.230E-01
NREG =             4 NPRCAP =             0 P1 =       -3.500E+08 W2 =       1.25
P2 =      -1.000E+09 DELP =               0.
P2 =      -2.400E+09 DELP =               0.
P2 =      -3.400E+09 DELP =               0.
P2 =      -1.533E+10 DELP =               0.

REBAR                RHOS=          2.5015E0 CFP=  100 DPY = 000 NVAR = 13
EQSTC=      1.576E11         0.0        0.0      2.0E0     0.25E0        0.0
FS=           0.05E0 THET=              0.0 IMC=                 3 IMS=              2

ALUMINUM               RHOS =     2.7        CFP=  000 DPY = 001 NVAR =  2
EQST =     6.670E+11 1.000E+12 1.220E+11 2.04E      0.25E      0.
YIELD =    3.210E+09 2.670E+11

(1)     K=     16     24     X=      7.62       17.78      17.78      7.62       MAT =    1
        J=      1      4     Y=      0.         0.         1.111      1.111
(2)     K=      6      8     X=      2.54       3.556      3.556      2.54       MAT =    3
        J=      1      4     Y=      0.         0.         1.111      1.111
(3)     K=      8      9     X=      3.556      4.064      4.064      3.556      MAT =    4
        J=      1      4     Y=      0.         0.         1.111      1.111
(4)     K=      9     13     X=      4.064      6.096      6.096      4.064      MAT =    3
        J=      1      4     Y=      0.         0.         1.111      1.111
(5)     K=     13     14     X=      6.096      6.604      6.604      6.096      MAT =    4
        J=      1      4     Y=      0.         0.         1.111      1.111
(6)     K=     14     16     X=      6.604      7.62       7.62       6.604      MAT =    3
        J=      1      4     Y=      0.         0.         1.111      1.111
(7)     K=      6      8     X=      2.54       3.556      3.556      2.540      MAT =    3
        J=      4     26     Y=      1.111      1.111      12.7       12.7
(8)     K=      8      9     X=      3.556      4.064      4.064      3.556      MAT =    4
        J=      4     26     Y=      1.111      1.111      12.7       12.7
(9)     K=      9     13     X=      4.064      6.096      6.096      4.064      MAT =    3
        J=      4     26     Y=      1.111      1.111      12.7       12.7
(10)    K=     13     14     X=      6.096      6.604      6.604      6.096      MAT =    4
        J=      4     26     Y=      1.111      1.111      12.7       12.7
(11)    K=     14     16     X=      6.604      7.62       7.62       6.604      MAT =    3
(1      J=      4     26     Y=      1.111      1.111      12.7       12.7
(12)    K=      1      6     X=      0.         2.54       2.54       0.         MAT =    3
        J=     14     26     Y=      8.89       6.378      12.7       12.7
(13) K =       24     26   X =       17.78      19.685     19.685     17.78      MAT =    5
     J =        1      4             0.         0.         1.111      1.111
(14) K =       24     26   X =       17.78      19.685     19.685     17.78      MAT =    5
     J =        4      7   Y =       1.111      1.111      2.475      2.475
(15) K =       24     26   X =       17.78      19.685     19.685     17.78      MAT =    5
     J =        7      8   Y =       2.475      2.475      3.1496     3.1496
(16) K =       26     37   X =       19.685     33.02      33.02      19.685     MAT =    5
     J =        7      8   Y =       2.475      2.475      3.1496     3.1496
 JU=                   4   KU =               16  UZERO =   -2.234E03
7/8/9
```

FIGURE C-6 IMPACT OF A CYLINDRICAL STEEL PROJECTILE ONTO A REINFORCED CONCRETE WALL

```
OSC-4 OIL SHALE(2ND 40GAL/TON SHOT), NO DAMAGE, RUN C
NSTAR    0 NPLOT 999 NDUMP   50 IMAX= 200 IPRIN  25
IJBUN=   2 NBLOC=  12 NMTRL    2 NJED=  14
TS =       5.000E-05 IVTYPE =          0 NVBLK =             0 KCHEK =             6
COSQ =     4.000E0   CLIN =    1.000E-01 TRIQ =    3.000E-02
KSLIDE   0 JSLIDE  0
JEDT,K,J=     1512 5    151213     1413 2    1413 6    1424 2    1524 5    1424 6
              152413    142413     1437 2    1537 6    1437 7    153713

PETN                RHOS =    5.390E-01 CFP = 000 DPY = 010 NVAR =  2
EQST =     1.000E0   0.        1.000E0   9.300E-01 9.300E-01
NTYPE =            12 QEXPL =  3.000E+10 5.000E0   0.        5.000E-01

OIL SHALE (40G/T)   RHOS =    2.000E0   CFP = 000 DPY = 001 NVAR =  2
EQST =     1.120E+11 1.120E+12 1.000E+11 1.240E0   2.500E-01-6.820E+11
YIELD =    1.000E+09 6.850E+10

(1)  K =     1     7 X =     0.        4.826     4.826     0.        MAT =   2
     J =     1     2 Y =     0.        0.        .292      .292
     K =     7    41 X =     4.826     24.384    24.384    4.826     MAT =   1
     J =     1     2 Y =     0.        0.        .292      .292
     K =    41    47 X =     24.384    29.21     29.21     24.384    MAT =   2
     J =     1     2 Y =     0.        0.        .292      .292
(1)  K =     1     7 X =     0.        4.826     4.826     0.        MAT =   2
     J =     2     7 Y =     .292      .292      1.78      1.78
     K =     7    41 X =     4.826     24.384    24.384    4.826     MAT =   2
     J =     2     7 Y =     .292      .292      1.78      1.78
     K =    41    47 X =     24.384    29.21     29.21     24.384    MAT =   2
     J =     2     7 Y =     .292      .292      1.78      1.78
(1)  K =     1     7 X =     0.        4.826     4.826     0.        MAT =   2
     J =     7    10 Y =     1.78      1.78      3.03      3.03
     K =     7    41 X =     4.826     24.384    24.384    4.826     MAT =   2
     J =     7    10 Y =     1.78      1.78      3.03      3.03
     K =    41    47 X =     24.384    29.21     29.21     24.384    MAT =   2
     J =     7    10 Y =     1.78      1.78      3.03      3.03
(1)  K =     1     7 X =     0.        4.826     4.826     0.        MAT =   2
     J =    10    20 Y =     3.03      3.03      8.73      8.73
     K =     7    41 X =     4.826     24.384    24.384    4.826     MAT =   2
     J =    10    20 Y =     3.03      3.03      8.73      8.73
     K =    41    47 X =     24.384    29.21     29.21     24.384    MAT =   2
     J =    10    20 Y =     3.03      3.03      8.73      8.73
7/8/9
```

FIGURE C-7 RUNNING DETONATION ALONG THE AXIS OF A CYLINDER OF OIL SHALE

Array sizes should be reset with KXX $\geqslant$ 47, JXX $\geqslant$ 20, and JSIZE $\geqslant$ 17000.

```
FRAGMENTING ROUND - SHOT NO. 2, RHOO(PETN)=1.2
NSTAR    0 NPLOT    5 NDUMP 999 IMAX=  50 IPRIN    5
IJBUN    2 NBLOC    7 NMTRL    6 NJED '    0
TS =       60.00E-06 IVTYPE =           0 NVBLK =            0 KCHEK =           6
COSQ =             4. CLIN =          0.1 TRIQ =           .05
KSLIDE   0 JSLIDE  0

PETN                 RHOS =           1.2 CFP = 000 DPY=   010 NVAR =   2
EQST =             1.          0.      0.        1.45      1.45
NTYPE =            2 Q =       3.580E+10         1.3       0.          2.

4340STEEL (SHEAR2)   RHOS =          7.85 CFP = 030 DPY=   001 NVAR=  63
EQST =     1.589E+12 5.170E+12 7.360E+10        1.69       .25 5.170E+13
SH2              30.        .2      .011        .001       5.        .07       .07
                 1.4 3.000E-08 3.000E+08         6.        .2        .17 7.000E+09
SIZE =      0    0    0    0    0    0    0    0    0
YIELD =    1.120E+10 8.190E+11

PMMA-8KB (BARKER)    RHOS =         1.184 CFP=  000 DPY=   001 NVAR =   2
EQST =     7.000E+10 4.050E+11 1.000E+10         1.        .25 3.640E+11
YIELD =    1.000E+06 1.950E+10

4140STEEL            RHOS =          7.85 CFP = 000 DPY=   001 NVAR=   2
EQST =     1.589E+12 5.170E+12 7.360E+10        1.69       .25 5.170E+13
YIELD =    6.000E+09 8.190E+11

LEAD (KOHN)          RHOS =        11.355 CFP = 000 DPY = 000
EQST =     5.008E+11 4.986E+11 9.155E+09         2.2       .25 2.019E+12

4340STEEL (SHEAR2)   RHOS =          7.85 CFP = 030 DPY=   001 NVAR = 63 NTRI =   1
EQST =     1.589E+12 5.170E+12 7.360E+10        1.69       .25 5.170E+13
SH2              30.        .2      .011        .001       5.        .07       .07
                 1.4 3.000E-08 3.000E+08         6.        .2        .17 7.000E+09
SIZE =      0    0    0    0    0    0    0    0    0
YIELD =    1.120E+10 8.190E+11

        K =       1    17 X =         1.905    13.335     15.24        0. MAT =    1
        J =       1     2 Y =           0.         0.      2.28      2.28
        K =       3    16 X =         1.905    14.288    14.288     1.905 MAT =    2
        J =       2     5 Y =         2.280     2.280      3.42      3.42
        K =       1     3 X =           0.      1.905     1.905        0. MAT =    6
        J =       2     5 Y =          2.28      2.28      3.42      3.42
        K =      16    17 X =        14.288     15.24     15.24    14.288 MAT =    6
        J =       2     5 Y =          2.28      2.28      3.42      3.42
        K =       1    17 X =           0.      15.24     15.24        0. MAT =    3
        J =       5     6 Y =          3.42      3.42      4.69      4.69
        K =       1    17 X =           0.      15.24     15.24        0. MAT =    4
        J =       6     8 Y =          4.69      4.69     10.16     10.16
        K =       1    17 X =           0.      15.24     15.24        0. MAT =    5
        J =       8    10  Y =        10.16     10.16      12.7      12.7
7/8/9
```

FIGURE C-8 RUNNING DETONATION OF PETN IN A STEEL FRAGMENTING CYLINDER CONTAINED IN CYLINDER OF PMMA, 4340 STEEL, AND LEAD

```
HF-1 FRAG ROUND WITH RUNNING DETONATION
NSTAR    0 NPLOT   20 NDUMP 999 IMAX= 200 IPRIN  20
IJBUND   2 NBLOCK 18 NMTRLS  3 NJED=
TS =       115.0E-06 IVTYPE=          0 NVBLK =           0 KCHEK =         12
COSQ=      4.0       CLIN =   0.1       TRIQ=           .05
KSLIDE   0 JSLIDE  0

HF-1                 RHOS =   7.85E0    CFP=  030 DPY=  002 NVAR = 64
EQST=      1.589E+12 5.170E+12 7.360E+10 1.69E0    0.25E0    5.170E+13
SH2        3.000E+01 .2000E+00 1.100E-02 1.000E-03 0.17      0.070E+00 0.070E+00
           1.4       3.000E-08 3.000E+08        6.        .2       .17 7.000E+09
NSIZE         0    0    0    8    8    8    0    0    0
YIELD =    1.030E+10 8.190E+11

PBXN-106             RHOS =   1.634     CFP = 000 DPY = 010 NVAR =  2
EQST =     1.        0.        0.        2.0       2.0       0.
NTYPE =            2 QEXPL =  3.900E+10 53.87     0.        2.0

CH6                  RHOS =   1.774     CFP = 000 DPY = 010 NVAR =  2
EQST =     1.        0.        0.        1.7       1.7       0.
NTYPE =            2 QEXPL =  5.811E+10 54.10     0.        2.0

1     K=       1    4 X =    0.        2.54      3.81      0.        MAT =   1
      J=       1    7 Y =    0.        0.        5.08      4.572
2     K=       4   12 X =    3.048     12.7      12.7      3.81      MAT =   1
      J=       4    7 Y =    2.108     4.318     6.35      5.08
3     K=       4   12 X =    2.54      12.7      12.7      3.048     MAT =   2
      J=       1    4 Y =    0.        0.        4.318     2.108
4     K=      12   29 X =    12.7      33.02     33.02     12.7      MAT =   1
      J=       4    7 Y =    4.318     4.318     6.35      6.35
5     K=      12   29 X =    12.7      33.02     33.02     12.7      MAT =   2
      J=       1    4  Y =   0.        0.        4.318     4.318
6     K=      29   43 X =    33.02     51.05     51.05     33.02     MAT =   1
      J=       4    7 Y =    4.318     1.651     4.064     6.350
7     K=      29   43 X =    33.02     51.05     51.05     33.02     MAT =   2
      J=       1    4 Y =    0.        0.        1.651     4.318
8     K=      43   46 X =    51.05     54.10     54.10     51.05     MAT =   1
      J=       4    7 Y =    1.651     1.651     3.505     4.064
9     K=      43   46 X =    51.05     54.10     54.10     51.05     MAT =   3
      J=       1    4 Y =    0.        0.        1.651     1.651
10    K=      46   47 X =    54.1      55.218    55.218    54.1      MAT =   1
      J=       2    7 Y =    0.5503333 0.        3.4086    3.505
11    K=      46   47 X =    54.1      54.659    55.218    54.1      MAT =   1
      J=       1    2 Y =    0.        0.        0.        0.5503333
12    K=      47   50 X =    55.218    58.572    58.572    55.218    MAT =   1
      J=       2    7 Y =    0.        0.        3.119     3.4086
13    K=      50   51 X =    58.572    59.69     59.69     58.572    MAT =   1
      J=       3    7 Y =    0.6238    0.        3.023     3.119
14    K=      50   51 X =    58.572    59.131    59.69     58.572    MAT =   1
      J=       2    3 Y =    0.        0.        0.        0.6238
15    K=      51   56 X =    59.69     66.04     66.04     59.69     MAT =   1
      J=       3    7 Y =    0.        0.        1.448     3.023
16    K=      56   57 X =    66.04     67.31     67.31     66.04     MAT =   1
      J=       4    7 Y =    0.362     0.        1.137     1.448
17    K=      56   57 X =    66.04     66.675    67.31     66.04     MAT =   1
      J=       3    4 Y =    0.        0.        0.        0.362
18    K=      57   58 X =    67.31     68.58     68.58     67.31     MAT =   1
      J=       4    7 Y =    0.        0.        0.8255    1.137
7/8/9
```

FIGURE C-9 SIMULATION OF A FRAGMENTING ROUND OF STANDARD MILITARY SHAPE

Array sizes should be reset with KXX $\geqslant$ 58, JXX $\geqslant$ 7, and JSIZE $\geqslant$ 19000.

Detonation of a standard military shell is simulated with the deck in Figure C.9. Material 3 is detonated first, then the detonation runs through the secondary explosive (material 2). The steel HF-1 is simulated by the shear band model so that a fragment size distribution is obtained at the end of the calculation. Note that three of the quadrilateral cells (blocks 11, 14, and 17) are laid out in the shape of triangles.

Most of the data decks shown can be run with the array dimensions shown in the listings: KXX = 40, JXX = 30, and JSIZE = 15000. However, for problems in Figs. C-7 and C-9, these dimensions must be augmented as shown in the figure subtitles. Matching array dimensions to problem size is further discussed in Section 5.5.

Appendix D

CALCULATIONS FOR EXPLOSIVES

This appendix outlines a simple detonation theory based on standard references such as Taylor.* Then the types of detonation provided in TROTT, the input required, and the algebra of the code calculations are described.

Background on Detonation Processes

Three substances are involved in a detonation process: the unreacted explosive, the reacting explosive, and the product gases. Here we will presume that the unreacted explosive and the product gases can be represented by equations of state with the pressure-volume isentropes shown in Figure D.1. During detonation, the chemical energy in the explosive is transformed to internal energy and the state point moved from the unreacted curve to the product curve of Figure D.1. In Chapman-Jouguet detonation theory, the reaction occurs within the shock front. In a steady detonation, the material follows a Rayleigh line from the initial density to a point of tangency on the products curve as shown. The point of tangency is the Chapman-Jouguet or C-J point. The pressure, volume, and energy at this point are labeled P_{CJ}, V_{CJ}, and E_{CJ}. If the product gases are assumed to follow a polytropic gas equation of state, that is,

$$PV^{\gamma} = \text{constant} \tag{D.1}$$

Then relations for the detonation velocity (D_x), P_{CJ}, E_{CJ}, and the particle velocity (u_{CJ}) can be derived. These are all derived from the polytropic gas relations, Hugoniot jump conditions, energy conservation, and the condition of tangency at the CJ point.

---

*J. Taylor, Detonation in Condensed Explosives (Clarendon Press, Oxford 1952).

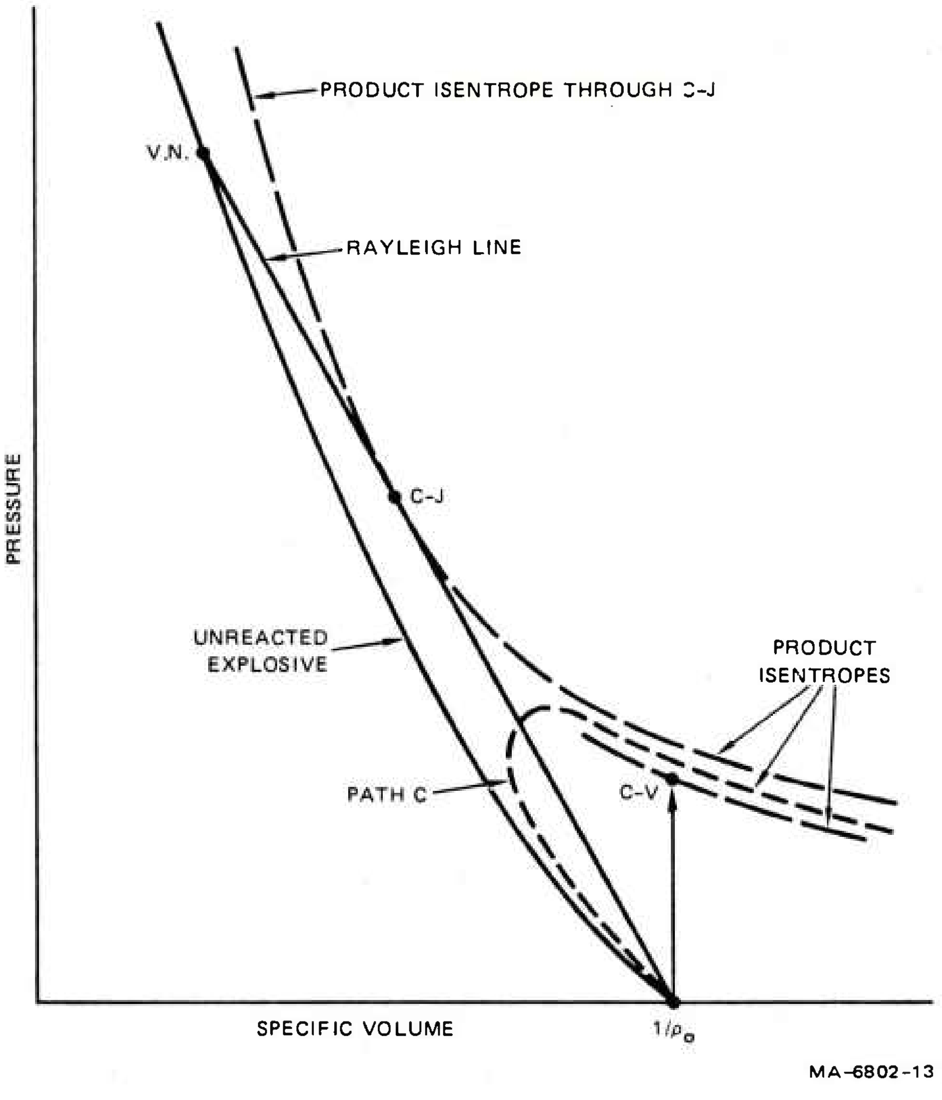


FIGURE D.1 PRESSURE-VOLUME PATHS FOLLOWED IN DETONATION PROCESS

$$D_x = \sqrt{2Q_x (\gamma + 1) (\gamma - 1)} \tag{D.2}$$

$$P_{CJ} = 2Q_x(\gamma - 1) \rho_o \tag{D.3}$$

$$V_{CJ} = \frac{\gamma}{\rho_o(\gamma + 1)} \tag{D.4}$$

$$E_{CJ} = \frac{2Q_x\gamma}{\gamma + 1} \tag{D.5}$$

$$u_{CJ} = \sqrt{\frac{2Q_x(\gamma - 1)}{\gamma + 1}} \tag{D.6}$$

where Q_x = the energy of the explosive

ρ_o = the initial density.

the polytropic gas exponent is related to the Grüneisen ratio as follows

$$\gamma = \Gamma + 1 \tag{D.7}$$

For many common explosives, γ values range from 2.5 to 3.0. This exponent describes the product gas isentrope adequately down to a few kilobars. For lower pressures, the apparent γ value decreases gradually to about 1.5 at ambient conditions.

Besides the Chapman-Jouguet process, several other detonation processes may occur in explosives. Von Neumann suggested that in a steady-state running detonation, the pressure in the shock rises to the point V.N. in Figure D.1 and then reduces gradually to C-J as the chemical reaction occurs. Path C is typical of computed pressure-volume paths followed during the buildup to a steady-state detonation. Here the chemical reaction is occurring during the loading by the stress wave. If the explosion occurs without a change in volume, the vertical path to the constant-volume point C-V is followed. The Chapman-Jouguet,

von Neumann, constant-volume, and various gradual detonation processes have all been used to represent explosive phenomena. Only the Chapman-Jouguet and constant-volume processes are currently available in TROTT.

The detonation type used in the calculation should match as nearly as possible the explosive behavior and geometry being considered. For example, if a block of explosive next to a plate is detonated at a point on the block opposite the plate, the detonation front will reach the plate as a plane wave; this process should be simulated as a running detonation. If the detonation occurs such that the wave front sweeps past the plate, however, a constant-volume explosion may give a better representation of the impulse applied to the plate. In some problems the stress histories in the explosive are not important (as in the impact of an explosively driven flyer plate); then a constant-volume calculation will adequately represent the impulse applied by the explosive.

Computation of Detonation Processes with the Subroutine EXPLODE

The Chapman-Jouguet and constant-volume detonation processes are incorporated into the EXPLODE subroutine. This routine may be called to perform three different functions: reading input, initializing cells, and computing the pressure for the running detonation.

The input for an explosive calculation includes NTYPE, Q_x, X_D, Y_D, and b, and is read during the first call to EXPLODE from LAYOUTT. NTYPE indicates the type of detonation:

NTYPE = 1 Constant volume explosion
= 2 Detonation along a line of constant x.
= 3 Detonation along a line of constant y.
= 4 Detonation from a point.

X_D and Y_D designate the initiation lines or points for a running detonation. The parameter b is the number of cells over which a detonation front is spread: nominal values of b are 2 to 4.

At the second call to EXPLODE, the energy and density of cells containing explosive are initialized. This call is made from LAYOUTT during the cell layout process. For a constant-volume explosion, the internal energy is equated to Q_x, and F_B = FBURN (the detonated fraction) is set to 1.0 to show that detonation has taken place.

For a running detonation, only cells near the detonation point or line are initialized at the second call to EXPLODE. The reacted fraction FBURN of a cell is computed based on the distance of the cell midpoint from the initiation point or line.

$$F_B = 1 - \frac{\left|\bar{Z} - Z_D\right|}{b\Delta Z} \tag{D.8}$$

where $\bar{Z}$ = the cell midpoint

Z_D = the initiation point

ΔZ = the cell length in the direction of propagation.

For the line initiations, the Z quantities are interpreted as the appropriate X or Y values. For a point detonation, $\bar{Z} - Z_D$ is the diagonal distance

$$\bar{Z} - Z_D = \sqrt{(X - X_D)^2 + (Y - Y_D)^2} \tag{D.9}$$

and ΔZ is the diagonal cell length

$$\Delta Z = \sqrt{\frac{[(\bar{X} - X_D)\Delta X]^2 + [(\bar{Y} - Y_D)\Delta Y]^2}{\bar{Z} - Z_D}} \tag{D.10}$$

where ΔX and ΔY are the cell dimensions. From Eq. (D.8) it appears that the cell midpoint must be within a distance of $b\Delta Z$ of the initiation point for any initiation to occur. For $F_B > 0$, the pressure, density, and internal energy are augmented to represent a point along the C-J detonation path in Figure D.1. Hence

$$P = P_{CJ}F_B \tag{D.11}$$

$$\rho = \frac{\rho_o}{1 + F_B(V_{CJ}\rho_o - 1)} \tag{D.12}$$

$$E = Q_x + (E_{CJ} - Q_x)F_b \tag{D.13}$$

This energy calculation appears adequate, although it is not justified analytically.

The third call to EXPLODE is made in SWEEPT. The purpose of the call is to compute pressure and energy during and following the reaction process. First, the time t_B to begin burning is computed.

$$t_B = \frac{|Z - Z_D| - b\Delta Z}{D_X} \tag{D.14}$$

The fraction detonated is then

$$F_B = \frac{(t - t_B)D_X}{b\Delta Z} \tag{D.15}$$

where t is the current problem time. Because of the absolute value sign in Eq. (D.14), the detonation can proceed in either direction from the initiation point or line. Given the detonated fraction F_B, the pressure and energy are computed both from the usual polytropic gas relations and as fractions of the C-J values. The pressure and energy values for the cell are taken as the maxima from these two calculations.

Appendix E

LISTING OF TROTT PROGRAM

The listing of the TROTT program includes the primary routines TROTT, LAYOUTT, SWEEPT, and SCRIBET plus some of the material model subroutines that may be used with TROTT. Listed here are EQST, EPLAS, REBAR, and EXPLODE. Other material models that may be used with TROTT are listed in Volume II of the final report, the manual for SRI PUFF 8.

PROGRAM TROTT

```
      PROGRAM TROTT (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1=1000,
     1   TAPE2,TAPE3,TAPE4,TAPE7=TAPE1,TAPE8=TAPE2,TAPE9=1000)
C
C     PROGRAM FOR 2-DIMENSIONAL PLANAR OR AXISYMMETRIC WAVE PROPAGATION
C     WITHOUT SLIDE LINES OR VERY LARGE DEFORMATION.  LAGRANGIAN, ARTIFI
C     VISCOSITY CODE WITH TRIANGLE Q. INTEGRATION BASED ON LEAPFROG SCHE
C     AND CONSTANT STRAIN QUADRILATERAL FINITE ELEMENTS.
C
C     WRITTEN MARCH 1976 BY L.SEAMAN.
C
      COMMON/EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6),
     1 EQSTS(6),RHO(6),RHOS(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,
     2 TRIQ,AMAT(6,4),SP(6),G2(6),PMIN(6)
      COMMON/NSCRB/SJ(60),NJED,NJKED,NKED,N,TIMEZ,DISCPT(20),JEDJ(60),
     1  JEDK(60),JEDT(60),NAME(60)
      COMMON/GEN/LZ(1),IJBUND,       JMAX,JMIN,KMAX,KMIN,UZERO,CALTIM,
     1   DELTIM,DT,DTN,TS,TYME,NSTART,NPLOT,NDUMP,IMAX,IPRINT
     2  ,KSKIP,KFULL,KPMAX,KPMIN,JPMAX,JPMIN,JSLIDE,KSLIDE
     3  ,NSCRIB,DTW,NEXED,NOBLQ,TANTH,JPRINT,JPR,JP1(20),JP2(20),KCHEK
     4  ,NBND,IBDJ1(6),IBDJ2(6),IBDK1(6),IBDK2(6),IBDX(6),IBDY(6),
     5   XFIX(6),YFIX(6)
      COMMON/CAL/ LISTE,LISTS,LISTX,LISTXD,CALE,CALS,CALX,CALXD
      COMMON/IND/NCMP(6),NFR(6),NPOR(6),NDS(6),NPR(6),NVAR(6),NTRI(6)
      COMMON/TSR/TSR(6,21),BFR(6,20)
      REAL MU
      DIMENSION X(1),Y(1),XD(1),YD(1),M(1),A(1),Z(1),D(1),SXX(1),SYY(1),
     1  SZZ(1),TXY(1),TXX(1),TYY(1),TZZ(1),P(1),E(1),TH(1),FS(1),DSTL(1)
     2  ,SRS(1),ZEVP(1),TEVP(1),YY(1),ROLD(1),IH(1),ENM(1),ENT(1),
     3  ICOM(1),CLB(1),CL1(1),CN(1),FF(1)
      EQUIVALENCE (COM,ICOM),(COM(1), X),(COM(2),Y),(COM(3),XD),
     1  (COM(4),YD),(COM(5),M),(COM(6),A),(COM(7),Z),(COM(8),D),(COM(9),
     2  SXX),(COM(10),SYY),(COM(11),SZZ),(COM(12),TXY),(COM(13),TXX),
     3  (COM(14),TYY),(COM(15),TZZ),(COM(16),P),(COM(17),E),(COM(18),
     4  IH),(COM(19),YY),(COM(20),TH),(COM(21),ZEVP),(COM(22),TEVP),
     5  (COM(23),FS),(COM(24),DSTL),(COM(25),ROLD),(COM(26),SRS),
     6  (COM(22),ENM),(COM(23),ENT),(COM(23),CLB),(COM(28),CL1),(COM(33)
     7  ,CN),(COM(21),FF)
C
C        COMMON AREAS WHICH MUST BE REDIMENSIONED TO MATCH PROBLEM SIZE
      COMMON/T/COM(15000)
      DIMENSION XL(40,30),YL(40,30),MM(40,30),IZ(40,30),LVAR(40,30)
      DATA (NAME(I), I=1,55)/3H  X,3H  Y,3H XD,3H YD,3(3H   ),3H  D,
     1  3HDSX,3HDSY,3HDSZ,3HTXY,3HTXX,3HTYY,3HTZZ,3H  P,3H  E,3H IH,
     2  3H YY,3H TH,3H21*,3H22*,3H23*,3H24*,3H25*,3H26*,3H27*,3H28*,
     3  3H29*,3H30*,3H31*,3H32*,3H33*,3H34*,3H35*,3H36*,3H37*,3H38*,
     4  3H39*,3H40*,5(3H   ),3H EX,3H EY,3H EZ,3HEXY,3H  Q,3H SX,3H SY,
     5  3H SZ,3HSTS,3HSTN/
C        ALSO SET JSIZE, JXX, KXX
C     IF JXX EXCEEDS 100, RESET DIMENSION OF XDTEMP IN SWEEP
      JSIZE=15000
      JXX=30
      KXX=40
      JK=JXX*KXX
C
      DISCPT(1)=5H  DAT
      DISCPT(2)=5HE =
      CALL DATE(DISCPT(3))
      DISCPT(4)=SHIFT(DISCPT(3),30)
 10   CALL SECOND(TIMEZ)
C*********                                                ************
C             I N I T I A L I Z A T I O N   IN  LAYOUTT
C
      CALL LAYOUTT(JSIZE,JXX,KXX,XL,YL,MM,IZ,LVAR)
C
      NC=3
      IF (NPLOT .LT. 900) GO TO 180
80    IF (IMAX .EQ. 0) GO TO 10
      WRITE (4) DISCPT,JEDT,JEDK,JEDJ
      N=0
      NSCRIB=0
      NC=1
      TIM=TIMEZ
      DT=1.E-12
      DTN=DT
```

```
  100 N=N+1
      CALL SECOND(TNOW)
      CALTIM=TNOW-TIMEZ
      DELTIM=TNOW-TIM
      TIM=TNOW
      TYME=TYME+DT
      IF (TYME .GE. TS .OR. N .GE. IMAX) IPRINT=N
C*********                                                  ************
C              C O M P U T A T I O N S   IN SWEEPT
C
      CALL SWEEPT(JSIZE,JXX,KXX,XL,YL,MM,IZ,LVAR)
C
      TG=TYME *1.E6
C*********                                                  ************
C              WRITE TAPE4 FOR SCRIBE HISTORIES AND PLOT HISTORIES
      WRITE (4) N,TG,DT,DELTIM,(SJ(I), I=1,NJED)
      IF (NEXED .EQ. 0) GO TO 150
C*********                                                  ************
C              WRITE THE EXTRA EDIT
      IF (MOD(N,NEXED) .EQ. 0) GO TO 140
      IF (JPRINT .EQ. 0) GO TO 150
      IF (N .LT. JP1(JPR) .OR. N .GT. JP2(JPR)) GO TO 150
140   PRINT 1140,N,TYME
      DO 148 K=1,KMAX
      PRINT 1142,K
      DO 148 J=2,JMAX
      IF (MM(K,J) .LE. 0) GO TO 148
      LM=LVAR(K,J)
      MAT=MM(K,J)
      IF (NVAR(MAT) .LE. 1) GO TO 148
      NV1=LM+18
      NV2=NVAR(MAT)+LM+17
      PRINT 1145,J,(COM(I),I=NV1,NV2)
148   CONTINUE
      IF (NC .GT. 1) GO TO 205
150   CONTINUE
C*********                                                  ************
C      DUMP FOR RESTART
      IF (NDUMP .NE. 0 .AND. MOD(N,NDUMP) .EQ. 0)WRITE(9)(COM(I),I=1,
     1 JSIZE),(LVAR(I),I=1,JK),(MM(I),I=1,JK),JMAX,JMIN,KMAX,KMIN,TYME
C
C      WRITE PLOT FILE
      IF (N .EQ. JP2(JPR)) JPR=JPR+1
C
C      CHECK STOP CRITERIA
      IF (NSCRIB .GT. 0)  GO TO 200
      IF (TYME .GE.  TS)  GO TO 200
      IF(N .GE. IMAX)  GO TO 200
      IF (MOD(N,NPLOT) .NE. 0) GO TO 195
C*********                                                  ************
C              WRITE TAPE 3 FOR  X-Y  PLOTS
180   DO 190 K=1,KMAX
      JMIN=0
      DO 185 J=1,JMAX
      IF (LVAR(K,J) .EQ. -1) GO TO 190
      IF (LVAR(K,J) .EQ. 0) GO TO 185
      IF (JMIN .EQ. 0) JMIN = J
      LM=LVAR(K,J)
      XL(K,J)=X(LM)
      YL(K,J)=Y(LM)
      IZ(K,J)=IH(LM)
185   CONTINUE
190   CONTINUE
      WRITE (3) N,TYME,((XL(K,J),YL(K,J), IZ(K,J), J=1,JMAX),K=1,KMAX)
195   CONTINUE
      IF (NC-2) 197,210,80
C
C     SET TIME STEP FOR NEXT CYCLE
197   DTN=DT
      DT=AMIN1(0.9*DTW,AMAX1(1.2*DT,0.035*DTW))
      DTN=0.5*(DT+DTN)
      IF (DT .GT. 1.E-12) GO TO 100
C
C     PREPARE FOR HISTORICAL LISTING AT END OF COMPUTATION
200   CALL SECOND(TNOW)
```

```
C*********                                                  ************
C       FINAL DUMP FOR RESTART
        IF (NDUMP .NE. 0 .AND. MOD(N,NDUMP) .NE. 0)WRITE(9)(COM(I),I=1,
      1 JSIZE),(LVAR(I),I=1,JK),(MM(I),I=1,JK),JMAX,JMIN,KMAX,KMIN,TYME
        NC=2
        CALTIM=TNOW-TIMEZ
        IF (NEXED .GT. 0) GO TO 140
205     CONTINUE
        IF (NPLOT .LT. 900) GO TO 180
210     PRINT 1200,IMAX,TS,CALTIM,N,TYME,DT,NSCRIB
        IF (NJED .LE. 0) GO TO 250
        DO  225 I=1,NJED
           JT=JEDT(I)
        IF (JT .LT. -40) JEDT(I)=NAME(-JT)
        IF (JT .GT. 0 .AND. JT .LE. 20) JEDT(I)=NAME(JT)
        IF (JT .GT. 20) ENCODE(3,1250,JEDT(I)) JT
1250    FORMAT(A3)
225     CONTINUE
 250    CONTINUE
        CALL SECOND(TNOW)
        CALTIM=TNOW-TIMEZ
        CALL SCRIBET
        GO TO 10
1140    FORMAT (//21H EXTRA EDIT AT CYCLE  I4,7H, TYME=1PE10.3)
1142    FORMAT (3X,1HJ,10X,9HCOLUMN K= I4)
1145    FORMAT (1X,I3,1P10E12.3/(1X,10E12.3))
 1200 FORMAT(//* STOP CRITERIA - IMAX =*,I4,4X,*TS =*,1PE10.3,
      - *  DT LESS THAN 1.E-12  NSCRIB = 1*,4X,*CALTIM =*,1PE10.3,
      -    * SECONDS*/*   CURRENT VALUES - N =*,I4,*  TYME =*,1PE10.3,
      - *  DT      = *,1PE10.3,*  NSCRIB =*,I2)
        END
```

SUBROUTINE EPLAS

```
       SUBROUTINE EPLAS(J,I,M,SR3,PS,DES,ESC,D,Y)
      DIMENSION ESC(6,20),DES(4),SR3(4)
C     I  X,Z,Y,XZ
C     DES(I)  DEVIATOR STRAIN INCREMENTS
C     SR3(I)  DEVIATOR STRESSES
C     ESC(M,1)=RHOO ESC(M,2)=C ESC(M,3)=D ESC(M,4)=S ESC(M,5)=SHEAR MOD
C     ESC(1,6)=  WORK HARDENING MODULUS
C     D DENSITY  AFTER STRAIN
C     Y  YIELD
C     Y=ESC(M,7)
      U=D/ESC(M,1)-1.
C     COMPUTE NEW PRESSURE
      PS= ESC(M,2)*U+ESC(M,3)*U**2+ESC(M,4)*U**3
      DEPSM=(DES(1)+DES(2)+DES(3))/3.
C     COMPUTE STRESSES IF STRAINS ARE ELASTIC
      SR3(1)=SR3(1)+2.*ESC(M,5)*(DES(1)-DEPSM)
      SR3(2)=SR3(2)+2.*ESC(M,5)*(DES(2)-DEPSM)
      SR3(3)=SR3(3)+2.*ESC(M,5)*(DES(3)-DEPSM)
      SR3(4)=SR3(4)+2.*ESC(M,5)*DES(4)
      SR3EFF=SQRT(3./2.*(SR3(1)**2+SR3(2)**2+SR3(3)**2+2.*SR3(4)**2))
C     TEST FOR YIELD
      IF  (SR3EFF .LE. Y ) GO TO 30
C     COMPUTE YIELD WITH WORK HARDENING
      Y=Y+ESC(M,6)*(SR3EFF-Y)/(2*ESC(M,5)+ESC(M,6))
C     COMPUTE STRESSES IF STRAINS ARE PLASTIC
      SR3(1)=SR3(1)*Y/SR3EFF
      SR3(2)=SR3(2)*Y/SR3EFF
      SR3(3)=SR3(3)*Y/SR3EFF
      SR3(4)=SR3(4)*Y/SR3EFF
   30 CONTINUE
      RETURN
      END
```

SUBROUTINE EQST

```
      SUBROUTINE EQST(E,D,P,M)                                          EQST       2
      COMMON/EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6), EQSCOM     2
     1  EQSTS(6),RHO(6),RHOS(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ, EQSCOM     3
     2  TRIQ,AMAT(6,4),SP(6),G2(6),PMIN(6)                              EQSCOM     4
      EMU=D/RHOS(M)-1.                                                  EQST       4
      PH=EMU*(EQSTC(M)+EMU*(EQSTD(M)+EMU*EQSTS(M)))                     EQST       5
      P=PH*(1.-0.5*EQSTG(M)*(1.-RHOS(M)/D))+EQSTG(M)*RHOS(M)*E          EQST       6
      RETURN                                                            EQST       7
      END                                                               EQST       8
```

```
      SUBROUTINE EXPLODE (NCALL,IN,M,E,D,DOLD,P,Q,FBURN,X,DX,Y,DY,J,K,
     1 TIME)
C
C     INITIALIZATION DEFINITIONS
C       X,Y  CELL CENTERS
C       DX,DY  CELL DIMENSIONS
C       TIME = TBURN,TIME WHEN DETONATION REACHES CELL
C     DEFINITIONS FOR SWEEP COMPUTATIONS
C       X = TBURN,DETONATION TIME
C       DX = CELL DIMENSION
C       TIME = PROBLEM TIME
      COMMON/EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6),
     1 EQSTS(6),RHO(6),RHOS(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,
     2 TRIQ,AMAT(6,4),SP(6),G2(6),PMIN(6)
      DIMENSION DET(6),DIST(6),ECJ(6),PCJ(6),QEXPL(6),VCJ(6),XDET(6),
     1 YDET(6),NTYPE(6)
      IF (NCALL-2) 100,200,300
C
C        READ DATA AND INITIALIZE MATERIAL VARIABLES    (NCALL=1)
C
100   READ (IN,1000) A1,A2,NTYPE(M),A3,A4,QEXPL(M),XDET(M),YDET(M),
     1 DIST(M)
      PRINT 1500,    A1,A2,NTYPE(M),A3,A4,QEXPL(M),XDET(M),YDET(M),
     1 DIST(M)
      PRINT 1001,IN
      DET(M)=SQRT(2.*QEXPL(M)*EQSTG(M)*(EQSTG(M)+2.))
      E=DET(M)
      VCJ(M)=(EQSTG(M)+1.)/((EQSTG(M)+2.)*RHO(M))
      ECJ(M)=2.*(EQSTG(M)+1.)*QEXPL(M)/(EQSTG(M)+2.)
      PCJ(M)=2.*RHO(M)*QEXPL(M)*EQSTG(M)
      PRINT 1501,DET(M),VCJ(M),ECJ(M),PCJ(M)
      RETURN
C
C        INITIALIZE CELL VARIABLES    (NCALL=2)
C
200   NTYP=NTYPE(M)-(NTYPE(M)/10)*10
      GO TO (210,220,230,240) NTYP
C        CONSTANT VOLUME EXPLOSION          (NTYPE=1)
210   E=QEXPL(M)
      FBURN=1.
      RETURN
C        DETONATION ALONG A LINE OF CONSTANT -X-     (NTYPE=2)
220   DZ=ABS(DX)*DIST(M)
      TBURN=(ABS(X-XDET(M))-DZ)/DET(M)
      IF (TBURN .GE. 0.) GO TO 280
      FBURN=AMIN1(1.,-TBURN*DET(M)/DZ)
      GO TO 250
C        DETONATION ALONG A LINE OF CONSTANT -Y-     (NTYPE=3)
230   DZ=ABS(DY)*DIST(M)
      TBURN=(ABS(Y-YDET(M))-DZ)/DET(M)
      IF (TBURN .GE. 0.) GO TO 280
      FBURN=AMIN1(1.,-TBURN*DET(M)/DZ)
      GO TO 250
C        DETONATION FROM A POINT           (NTYPE=4)
240   XH=X
      YH=Y
      ZH=SQRT((XH-XDET(M))**2+(YH-YDET(M))**2)
      IF (ZH .LT. 1.E-4) GO TO 248
      DZ=DIST(M)*SQRT(((XH-XDET(M))*DX)**2+((YH-YDET(M))*DY)**2)/ZH
      TBURN=(ZH-DZ)/DET(M)
      IF (TBURN .GE. 0.) GO TO 280
      FBURN=AMIN1(1.,-TBURN*DET(M)/DZ)
      GO TO 250
248   FBURN=1.
250   IF (NTYPE(M) .GT. 10) GO TO 270
      E=QEXPL(M)+(ECJ(M)-QEXPL(M))*FBURN
      D=RHO(M)/(1.-FBURN*(1.-VCJ(M)*RHO(M)))
      P=PCJ(M)*FBURN
260   PRINT 1555,K,J,FBURN,TBURN,XH,E,D,P
1555  FORMAT (*  K,J=*2I4,* FBURN=*F6.4,* TBURN=*1PE11.3,* XH=*E11.3,
     1 * E=*E11.3,* D=*E11.3,* P=*E11.3)
      GO TO 280
270   E=QEXPL(M)*FBURN
      P=EQSTG(M)*D*E
```

SUBROUTINE EXPLODE (Concluded)

```
      GO TO 260
 280  TIME=TBURN
      DX=DZ
      RETURN
C
C        COMPUTE DETONATION PROCESS         (NCALL=3)
C
 300  IF (FBURN .GT. 0.999) GO TO 310
      NTYP=NTYPE(M)-(NTYPE(M)/10)*10
      IF (NTYP .GT. 1) GO TO 320
C        PRESSURE IN EXPLOSION PRODUCTS
 310  P=EQSTG(M)*D*E
      RETURN
 320  TBURN=X
      FB=AMIN1(1.,AMAX1((TIME-TBURN)*DET(M)/DX,
     1   (1.-RHO(M)/D)/(1.-VCJ(M)*RHO(M)),FBURN))
      IF (FB .LT. 0.4) RETURN
 352  HDV=0.5*(1./DOLD-1./D)
      POLD=P
      P=EQSTG(M)*D*(E+POLD*HDV+QEXPL(M)*(FB-FBURN)+Q*2.*HDV)/
     1   (1.-EQSTG(M)*HDV*D)
      E=E+(P+POLD)*HDV+QEXPL(M)*(FB-FBURN)+2.*Q*HDV
      IF (NTYPE(M) .GT. 10) GO TO 360
      P=AMAX1(P,PCJ(M)*FB)
      E=AMAX1(E,ECJ(M)*FB)
 360  FBURN=FB
      IF (FB .GE. 0.999) PRINT 1350,K,J,D
      RETURN
1000  FORMAT (2A5,I10,2A5,5E10.3)
1001  FORMAT (1H+,79X,12H IND=   , IN=I2,10H -EXPLODE-)
1350  FORMAT (27H DETONATION COMPLETED AT K=I3,3H J=I3,9H DENSITY=
     1   1PE10.3)
1500  FORMAT(2A5,I10,2A5,1P5E10.3)
1501  FORMAT (10X,33HFROM EXPLODE, DET, VCJ, ECJ, PCJ=1P4E10.3)
      END
```

```
      SUBROUTINE LAYOUTT(JSIZE,JXX,KXX,XL,YL,MM,IZ,LVAR)
C
C     ROUTINE READS IN DATA FOR EACH PROBLEM AND LAYS OUT COORDINATE ARR
C
      COMMON/GEN/LZ(1),IJBUND,       JMAX,JMIN,KMAX,KMIN,UZERO,CALTIM,
     1   DELTIM,DT,DTN,TS,TYME,NSTART,NPLOT,NDUMP,IMAX,IPRINT
     2  ,KSKIP,KFULL,KPMAX,KPMIN,JPMAX,JPMIN,JSLIDE,KSLIDE
     3  ,NSCRIB,DTW,NEXED,NOBLQ,TANTH,JPRINT,JPR,JP1(20),JP2(20),KCHEK
     4  ,NBND,IBDJ1(6),IBDJ2(6),IBDK1(6),IBDK2(6),IBDX(6),IBDY(6),
     5   XFIX(6),YFIX(6)
      COMMON/CAL/ LISTE,LISTS,LISTX,LISTXD,CALE,CALS,CALX,CALXD
      COMMON/IND/NCMP(6),NFR(6),NPOR(6),NDS(6),NPR(6),NVAR(6),NTRI(6)
      COMMON/TSR/TSR(6,21),BFR(6,20)
      COMMON/NSCRB/SJ(60),NJED,NJKED,NKED,N,TIMEZ,DISCPT(20),JEDJ(60),
     1  JEDK(60),JEDT(60),NAME(60)
      COMMON/EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6),
     1  EQSTS(6),RHO(6),RHOS(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,
     2  TRIQ,AMAT(6,4),SP(6),G2(6),PMIN(6)
      REAL MU
      COMMON/T/COM(1000)
      DIMENSION XA(4),YA(4),XL(KXX,JXX),YL(KXX,JXX),MM(KXX,JXX),IZ(KXX,
     1 JXX),LVAR(KXX,JXX)
      DIMENSION X(1),Y(1),XD(1),YD(1),M(1),A(1),Z(1),D(1),SXX(1),SYY(1),
     1  SZZ(1),TXY(1),TXX(1),TYY(1),TZZ(1),P(1),E(1),TH(1),FS(1),DSTL(1)
     2  ,SRS(1),ZEVP(1),TEVP(1),YY(1),ROLD(1),IH(1),ENM(1),ENT(1),
     3  ICOM(1),CLB(1),CL1(1),CN(1)
      EQUIVALENCE (COM,ICOM),(COM(1), X),(COM(2),Y),(COM(3),XD),
     1  (COM(4),YD),(COM(5),M),(COM(6),A),(COM(7),Z),(COM(8),D),(COM(9),
     2  SXX),(COM(10),SYY),(COM(11),SZZ),(COM(12),TXY),(COM(13),TXX),
     3  (COM(14),TYY),(COM(15),TZZ),(COM(16),P),(COM(17),E),(COM(18),
     4  IH),(COM(19),YY),(COM(20),TH),(COM(21),ZEVP),(COM(22),TEVP),
     5  (COM(23),FS),(COM(24),DSTL),(COM(25),ROLD),(COM(26),SRS),
     6  (COM(22),ENM),(COM(23),ENT),(COM(23),CLB),(COM(28),CL1),(COM(33)
     7  ,CN),(COM(21),FF)
      DATA LISTE,LISTS,LISTX,LISTXD,CALE,CALS,CALX,CALXD/5HKJ/KG,3HGPA
     1  ,2HCM,5HM/SEC,1.E-7,1.E-7,1.,1.E-2/
C
C     XA(1)=XL(K1,J1),  XA(2)=XL(K2,J1),XA(3)=XL(K2,J2),XA(4)=XL(K1,J2)
C
      DO 102  I=1,JSIZE
102   COM(I)=0.
      JK=JXX*KXX
      DO 104 I=1,JK
      XL(I)=-999.
      YL(I)=-999.
      MM(I)=0
104   LVAR(I)=0
      DO 106  I=1,237
106   EQSTC(I)=0.
      DO 107  I=1,246
107   TSR(I)=0.
      DO 108  I=1,36
108   NCMP(I)=0
      DO 109 I=1,245
109   SJ(I)=0.
      DO 111  I=1,66
111   LZ(I)=0
      KMAX=KXX
      JMAX=JXX
      READ 1100,(DISCPT(I), I=5,20)
      IF (EOF(5)) 105,110
 105   PRINT 1001
      STOP 2020
 110  PRINT 1000
      PRINT 1100, (DISCPT(I), I=1,4)
      PRINT 1100, (DISCPT(I), I=5,20)
      READ 1105,A1,NSTART,A2,NPLOT,A3,NDUMP,A4,IMAX,A5,
     1  IPRINT,A6,JPRINT,A7,NEXED,A8,NOBLQ
      PRINT 1105,A1,NSTART,A2,NPLOT,A3,NDUMP,A4,IMAX,A5,
     1  IPRINT,A6,JPRINT,A7,NEXED,A8,NOBLQ
      IF (NOBLQ .EQ. 0) GO TO 115
      READ 1104,A1,A2,ANGLE
      PRINT 1104,A1,A2,ANGLE
      TANTH=TAN(ANGLE/57.2957795)
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115   CONTINUE
C                 IJBUND DEFINITION
C        BOUNDARY CONDITION                  AXISYMMETRIC          PLANAR
C           FIXED YVEL AT JMAX,JMIN               1                  -1
C           FIXED YVEL AT JMIN ONLY               2                  -2
C           FREE EDGES                            -                  -3
C           FIXED YVEL AT JMIN ,                  4                  -4
C              FIXED XVEL AT KMAX, KMIN
C           FIXED YVEL AT JMIN, JMAX,             5                  -5
C              FIXED XVEL AT KMIN
C           FIXED YMIN, XMIN                      6                  -6
C                 IVTYPE DEFINITION
C        1  INITIALIZE X VELOCITY UP TO KU, SET INTERFACE
C             VELOCITY AT KU
C       -1  INITIALIZE X VELOCITY FROM KU TO KMAX, SET
C             INTERFACE VELOCITY AT KU
C        2  INITIALIZE X AND Y VELOCITIES BY BLOCKS, INTERPOLATING IN
C             X AND Y.  NO INTERFACE PROVISION
C     IPRIND CAUSES A CARD TO BE READ WHICH SETS SPECIAL PRINT OPTIONS
C      KSKIP SKIPS K COLUMNS IN THE PRINTOUT
C     KFULL GIVES FULL K LISTING AMONGST SKIPPED K LISTINGS
C     KPMAX AND KPMIN SET THE MAXIMUM AND MINIMUM K ROWS TO BE PRINTED
C     JPMAX AND JPMIN SET THE MAXIMUM AND MINIMUM J COLUMNS TO BE
C           PRINTED
      KSKIP =1
      KFULL=1
      KPMAX=KMAX
      KPMIN=KMIN=1
      JPMAX=JMAX
      JPMIN=JMIN=1
      READ 1106,A1,A2,IJBUND,A3,A4,NBLOCK,A5,A6,NMTRLS,A7,A8,NJED
     1 ,A9,A10,IPRIND,A11,A12,NEXTRA
      PRINT 1106,A1,A2,IJBUND,A3,A4,NBLOCK,A5,A6,NMTRLS,A7,A8,NJED
     1 ,A9,A10,IPRIND,A11,A12,NEXTRA
      READ  1108,A1,A2,TS,A3,A4,IVTYPE,A5,A6,NVBLK,A7,A8,KCHEK
      PRINT 1108,A1,A2,TS,A3,A4,IVTYPE,A5,A6,NVBLK,A7,A8,KCHEK
      READ  1104,A1,A2,CQSQ,A3,A4,CLIN,A5,A6,TRIQ
      PRINT 1104,A1,A2,CQSQ,A3,A4,CLIN,A5,A6,TRIQ
      READ  1106,A1,A2,KSLIDE,A3,A4,JSLIDE,A5,A6,NBND,A7,A8,ICAL
      PRINT 1106,A1,A2,KSLIDE,A3,A4,JSLIDE,A5,A6,NBND,A7,A8,ICAL
      IF (NBND .LE. 0) GO TO 135
      DO 133 I=1,NBND
      READ 1133,A1,A2,IBDK1(I),IBDK2(I),A3,A4,IBDJ1(I),IBDJ2(I),A5,A6,
     1  IBDX(I),IBDY(I),XFIX(I),YFIX(I)
      PRINT 1133,A1,A2,IBDK1(I),IBDK2(I),A3,A4,IBDJ1(I),IBDJ2(I),A5,A6,
     1  IBDX(I),IBDY(I),XFIX(I),YFIX(I)
133   CONTINUE
135   IF (ICAL .LE. 0) GO TO 140
      READ  1109,A1,A2,LISTE,LISTS,LISTX,LISTXD
      PRINT 1109,A1,A2,LISTE,LISTS,LISTX,LISTXD
      READ  1107,A1,A2,CALE,CALS,CALX,CALXD
      PRINT 1107,A1,A2,CALE,CALS,CALX,CALXD
140   CONTINUE
      IF (JPRINT .EQ. 0) GO TO 145
      READ 1112,A1,A2,(JP1(I),JP2(I), I=1,JPRINT)
      PRINT 1112,A1,A2,(JP1(I),JP2(I), I=1,JPRINT)
      JPR=1
145   IF (NJED .EQ. 0) GO TO 155
      N1=1
150   N2=MINO(N1+6,NJED)
      IF (N2 .LE. 60)  READ 1125, A1,A2,(JEDT(I),JEDK(I), JEDJ(I),
     -   I=N1,N2)
      IF (N2  .GT.  60)  READ 1110,A1
      PRINT 1125, A1,A2, (JEDT(I),JEDK(I),JEDJ(I),  I=N1,N2)
      N1=N2+1
      IF (N2 .LT. NJED) GO TO 150
155   NJED=MINO(NJED,98)
      NJKED=NJED
      IF (IPRIND .LE. 0) GO TO 160
      READ  1111,A1,A2,KSKIP,A3,A4,KFULL,A5,A6,KPMAX,A7,A8,KPMIN,
     1  A9,A10,JPMAX,A11,A12,JPMIN
      PRINT 1111,A1,A2,KSKIP,A3,A4,KFULL,A5,A6,KPMAX,A7,A8,KPMIN,
     1  A9,A10,JPMAX,A11,A12,JPMIN
160   LSHB=0
      DO 200 L=1,NMTRLS
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          READ 1130, (AMAT(L,I), I=1,4), A1,A2,RHOS(L),A3,A4,NCMP(L),
     1  NFR(L),NPOR(L),A5,A6,NDS(L),NPR(L),NYAM,A7,A8,NVAR(L),A9,A10,
     2  NTRI(L)
          RHO(L)=RHOS(L)
      PRINT 1002
          PRINT 1130,(AMAT(L,I), I=1,4), A1,A2,RHOS(L),A3,A4,NCMP(L),
     1  NFR(L),NPOR(L),A5,A6,NDS(L),NPR(L),NYAM,A7,A8,NVAR(L),A9,A10,
     2  NTRI(L)
          READ 1107, A1,A2,EQSTC(L),EQSTD(L),EQSTE(L),EQSTG(L),
     -    EQSTH(L),EQSTS(L),PMIN(L)
          PRINT 1107,A1,A2,EQSTC(L),EQSTD(L),EQSTE(L),EQSTG(L),
     -    EQSTH(L),EQSTS(L),PMIN(L)
      IF (NCMP(L) .GT. 0) CALL REBAR(-1,5,1,1,L,N,IH,RHO(L),DOLD,SSP,SY,
     1SZ,TXY,E,P,DEX,DEY,DEZ,DEXY,F,THETA,DTHETA,ESC,FS,DSTL,SRS,ZEVP,
     2  TEVP,YC(L),ROLD,IPRINT)
      IF (NFR(L) .EQ. 0) GO TO 180
      NFRM=NFR(L)
      GO TO (170,170,175,175,170,170,170) NFRM
170   CONTINUE
      READ 1107,A1,A2,(TSR(L,I),I=1,7)
      PRINT 1107,A1,A2,(TSR(L,I),I=1,7)
      IF (NFR(L) .NE. 2 .AND. NFR(L) .NE. 7) GO TO 180
      READ 1107,A1,A2,(TSR(L,I),I=8,14)
      PRINT 1107,A1,A2,(TSR(L,I),I=8,14)
      GO TO 180
175   CALL SHEAR2(LSHB,5,L,1,1,IH,SX,SY,SXY,P,A1,DH,DOLD,A2,E,A3,A4,
     1  A5,A6,EX,EY,EXY,F,A7,A8,A9,A10,A11,A12)
      LSHB=1
      IF (NFR(L) .EQ. 4) GO TO 170
180   IF (NPOR(L) .EQ. 0) GO TO 190
      READ 1104, A1, A2, RHO(L), A3, A4, MU(L)
      PRINT 1104,A1, A2, RHO(L), A3, A4, MU(L)
      IF (NPOR(L) .EQ. 4) GO TO 185
      CALL POREQST(0,5,L,SP(L),RHO(L),A2,A3,A4,A5,A6,A7,A8,A9,A10,
     1  EQSTC(L),EQSTD(L),EQSTG(L),EQSTS(L),A11,A12,A13)
      GO TO 190
185   CONTINUE
      CALL CAP1(-1,5,L,N,IH,DH,DOLD,E,EX,EY,EZ,EXY,SX,SY,SZ,SXY,ZEVP,
     1  K,J,TEVP)
190   CONTINUE
      IF (NDS(L) .EQ. 7) CALL EP(0,L,N)
      IF (NPR(L) .EQ. 1) CALL EXPLODE(1,5,L,SP(L),D(1),DOLD,P(1),Q,
     1  COM(19),X(1),DX,Y(1),DY,J,K,0.)
      IF (NYAM .EQ. 0) GO TO 195
          READ 1107, A1,A2, YC(L), MU(L),YAD(L)
          PRINT 1107,A1,A2, YC(L), MU(L),YAD(L)
195   IF (SP(L) .EQ. 0.) SP(L)=SQRT((EQSTC(L)+1.33333*MU(L))/RHO(L))
      IF (NCMP(L) .GT. 0) SP(L)=SSP
      ESC(L,1)=RHO(L)
      ESC(L,2)=EQSTC(L)
      ESC(L,3)=EQSTD(L)
      ESC(L,4)=EQSTS(L)
      ESC(L,5)=MU(L)
      ESC(L,6)=YAD(L)
      ESC(L,7)=RHOS(L)
      ESC(L,9)=EQSTG(L)
      ESC(L,10)=YC(L)
200   G2(L)=2.*MU(L)
C
C     CALL FOR ADDED DATA
      IF (NEXTRA .GT. 0) CALL EXTRAT(1)
C
C ******  CELL LAYOUT      ******
      PRINT 1800,SP
 1800 FORMAT(* SP=* 1P6E10.3)
      IF (NSTART .GE. 1) GO TO 500
C
      NSTDX=4
      NSTD=13
      DO 250  NB=1,NBLOCK
      READ 1030, A1,A2,K1,K2,A3,A4,(XA(I),I=1,4),A5,A6,MAT
      PRINT 1030,A1,A2,K1,K2,A3,A4,(XA(I),I=1,4),A5,A6,MAT
      READ 1030,  A1,A2,J1,J2,A3,A4,(YA(I),I=1,4)
      PRINT 1030, A1,A2,J1,J2,A3,A4,(YA(I),I=1,4)
      DJDK=(J2-J1)*(K2-K1)
```

```
      DO 210   K=K1,K2
      DO 210   J=J1,J2
      IF (XL(K,J) .EQ. -999.)XL(K,J)=((XA(1)*(J2-J)+XA(4)*(J-J1))*(K2-K)
     -+(XA(2)*(J2-J)+XA(3)*(J-J1))*(K-K1))/DJDK
      IF (YL(K,J) .EQ. -999.)YL(K,J)=((YA(1)*(J2-J)+YA(4)*(J-J1))*(K2-K)
     -+(YA(2)*(J2-J)+YA(3)*(J-J1))*(K-K1))/DJDK
      IF (K .GT. K1 .AND. J .GT. J1)  MM(K,J)=MAT
  210 CONTINUE
  250 CONTINUE
      LVARM=1
      JM=1
      DO 300  K=1,KMAX
      DO 280   J=1,JMAX
      IF (J .GT. 1  .AND. LVAR(K,J-1)  .GT. 0)  LVAR(K,J)=-1
      IF (XL(K,J).EQ.-999.  .OR. YL(K,J) .EQ. -999.) GO TO 280
      KM=K
      JM=MAXO(JM,J)
      LVAR(K,J)=LVARM
      X(LVARM)=XL(K,J)
      Y(LVARM)=YL(K,J)
      IH(LVARM)=2
      MAT=MM(K,J)
      IF (MAT .EQ. 0)  GO TO 260
      A124=0.5*(XL(K,J-1)*(YL(K,J)-YL(K-1,J))
     1-XL(K,J)*(YL(K,J-1)-YL(K-1,J))+XL(K-1,J)*(YL(K,J-1)-YL(K,J)))
      A234=0.5*(XL(K,J-1)*(YL(K-1,J)-YL(K-1,J-1))+XL(K-1,J)*
     -(YL(K-1,J-1)-YL(K,J-1))+XL(K-1,J-1)*(YL(K,J-1)-YL(K-1,J)))
      XZ=0.25*(XL(K,J)+XL(K,J-1)+XL(K-1,J)+XL(K-1,J-1))
      YZ=0.25*(YL(K,J)+YL(K,J-1)+YL(K-1,J)+YL(K-1,J-1))
       D(LVARM)=RHO(MAT)
      IF (YC(MAT) .NE. 0.) YY(LVARM)=YC(MAT)
      IF (NPR(MAT) .NE. 1) GO TO 255
      DX=X(LVARM)-XL(K-1,J)
      CALL EXPLODE(2,5,MAT,E(LVARM),D(LVARM),DOLD,P(LVARM),Q,COM(18+
     1  LVARM),XZ,DX,YZ,Y(LVARM)-YL(K,J-1),J,K,COM(LVARM+19))
      COM(LVARM+20)=DX
  255 CONTINUE
      IF (NTRI(MAT) .EQ. 0) GO TO 258
      M(LVARM)=LVARM+NSTDX+NSTD+NVAR(MAT)-5
      LVAR2=M(LVARM)
      D(LVAR2)=RHO(MAT)
      IF (NPR(MAT) .NE. 1) GO TO 256
      DX=X(LVARM)-XL(K-1,J)
      CALL EXPLODE(2,5,MAT,E(LVAR2),D(LVAR2),DOLD,P(LVAR2),Q,COM(18+
     1  LVAR2),XZ,DX,YZ,Y(LVARM)-YL(K,J-1),J,K,COM(LVAR2+19))
      COM(LVAR2+20)=DX
  256 CONTINUE
      A(LVARM)=A124
      A(LVAR2)=A234
      Z(LVARM)=D(LVARM)*A(LVARM)
      Z(LVAR2)=D(LVAR2)*A(LVAR2)
      IF (IJBUND .GT. 0) Z(LVARM)=D(LVAR2)*A124*(YL(K,J)+YL(K-1,J)+
     1   YL(K,J-1))
      IF (IJBUND .GT. 0) Z(LVAR2)=D(LVAR2)*A234*(YL(K-1,J)+YL(K-1,J-1)+
     1  YL(K,J-1))
      IF (YC(MAT) .NE. 0.) YY(LVAR2)=YC(MAT)
      LVARM=LVAR2
      GO TO 260
  258 A(LVARM)=A124+A234
      Z(LVARM)=D(LVARM)*A(LVARM)
C     Z IS COMPUTED AS 1.5/PI TIMES ACTUAL NUMBER FOR AXISYMMETRIC CASE
      IF (IJBUND .GT. 0) Z(LVARM)=D(LVARM)*(A124*(YL(K,J)+YL(K-1,J)+
     1 YL(K,J-1))+A234*(YL(K-1,J)+YL(K-1,J-1)+YL(K,J-1)))
  260 CONTINUE
      LVARM=LVARM+NSTDX
      IF (MAT .NE. 0)  LVARM=LVARM+NVAR(MAT)+NSTD
  280 CONTINUE
  300 CONTINUE
      KMAX=KM
      JMAX=JM
C
C ******* INITIALIZE VELOCITIES IN ONE BLOCK
C
      IF (IVTYPE .GT. 1) GO TO 350
      IF (IVTYPE .EQ. 0) GO TO 450
```

```
      READ 1032,A1,A2,JU,A3,A4,KU,A5,A6,UZERO
      PRINT 1032,A1,A2,JU,A3,A4,KU,A5,A6,UZERO
      AMASS=0.
      BMASS=0.
      UZINT=UZERO
      DO 310 J=2,JU
      IF (MM(KU,J) .LE. 0 .OR. MM(KU+1,J) .LE. 0) GO TO 310
      MA=MM(KU,J)
      MB=MM(KU+1,J)
      AMASS=AMASS+RHO(MA)*(XL(KU,J)-XL(KU-1,J))
      BMASS=BMASS+RHO(MB)*(XL(KU+1,J)-XL(KU,J))
310   CONTINUE
      IF (AMASS+BMASS .GT. 0..AND. IVTYPE .EQ.-1) UZINT=UZERO*BMASS/
     1  (AMASS+BMASS)
      IF (AMASS+BMASS .GT. 0..AND. IVTYPE .EQ. 1) UZINT=UZERO*AMASS/
     1  (AMASS+BMASS)
      DO 325 K=1,KMAX
      DO 325 J=1,JMAX
      IF (LVAR(K,J) .LE. 0) GO TO 320
      LM=LVAR(K,J)
      IF (K .GT. KU .AND. IVTYPE .EQ. -1) XD(LM)=UZERO
      IF (K .LT. KU .AND. IVTYPE .EQ. 1) XD(LM)=UZERO
      IF (J .LE. JU .AND. K .EQ. KU) XD(LM)=UZINT
320   CONTINUE
325   CONTINUE
      IF (KCHEK .NE. 0) GO TO 450
      KCHEK=KMAX
      IF (IVTYPE .EQ. 1) KCHEK=KU+3
      GO TO 450
C
C ******* INITIALIZE X AND Y VELOCITIES IN SEVERAL BLOCKS
350   CONTINUE
      DO 400 NB=1,NVBLK
      READ  1031,A1,A2,K1,K2,A3,A4,(XA(I),I=1,4)
      PRINT 1031,A1,A2,K1,K2,A3,A4,(XA(I),I=1,4)
      READ  1031,A1,A2,J1,J2,A3,A4,(YA(I),I=1,4)
      PRINT 1031,A1,A2,J1,J2,A3,A4,(YA(I),I=1,4)
      KCHEK=MAX0(KCHEK,K1+2,K2+2)
      IF (K1 .LT. K2) GO TO 370
      IF (J1 .LT. J2) GO TO 360
C         INITIALIZE VELOCITY AT ONE POINT
      LM=LVAR(K1,J1)
      XD(LM)=XA(1)
      YD(LM)=YA(1)
      GO TO 400
C         INITIALIZE VELOCITY AT SEVERAL J VALUES, ONE K
360   DY=YL(K1,J2)-YL(K1,J1)
      IF (ABS(DY) .LE. 1.E-06) GO TO 390
      DO 365 J=J1,J2
      LM=LVAR(K1,J)
      XD(LM)=(XA(1)*(YL(K1,J2)-YL(K1,J))+XA(2)*(YL(K1,J)-YL(K1,J1)))/DY
365   YD(LM)=(YA(1)*(YL(K1,J2)-YL(K1,J))+YA(2)*(YL(K1,J)-YL(K1,J1)))/DY
      GO TO 400
C         INITIALIZE VELOCITY AT SEVERAL K VALUES, ONE J
370   IF (J1 .LT. J2) GO TO 380
      DX=XL(K2,J1)-XL(K1,J1)
      IF (ABS(DX) .LE. 1.E-06) GO TO 390
      DO 375 K=K1,K2
      LM=LVAR(K,J1)
      XD(LM)=(XA(1)*(XL(K2,J1)-XL(K,J1))+XA(2)*(XL(K,J1)-XL(K1,J1)))/DX
375   YD(LM)=(YA(1)*(XL(K2,J1)-XL(K,J1))+YA(2)*(XL(K,J1)-XL(K1,J1)))/DX
      GO TO 400
C         INITIALIZE VELOCITY FOR SEVERAL J AND K VALUES
C     INTERPOLATION IS LINEAR IN J DIRECTION AND ON BOUNDARIES OF BLOCK
380   IF (ABS((XL(K2,J1)-XL(K1,J1))*(YL(K1,J2)-YL(K1,J1))*(XL(K2,J2)-
     1 XL(K1,J2))*(YL(K2,J2)-YL(K2,J1))) .LE. 1.E-25) GO TO 390
      DO 385 K=K1,K2
      DO 385 J=J1,J2
      LM=LVAR(K,J)
      XD(LM)=((XA(1)*(XL(K2,J1)-XL(K,J1))+XA(2)*(XL(K,J1)-XL(K1,J1)))
     1  /(XL(K2,J1)-XL(K1,J1))*(YL(K,J2)-YL(K,J)) + (XA(3)*(XL(K,J2)
     2  -XL(K1,J2))+XA(4)*(XL(K2,J2)-XL(K,J2)))/(XL(K2,J2)-XL(K1,J2))
     3  *(YL(K,J)-YL(K,J1)))/(YL(K,J2)-YL(K,J1))
385   YD(LM)=((YA(1)*(XL(K2,J1)-XL(K,J1))+YA(2)*(XL(K,J1)-XL(K1,J1)))
     1  /(XL(K2,J1)-XL(K1,J1))*(YL(K,J2)-YL(K,J)) + (YA(3)*(XL(K,J2)
```

```
     2  -XL(K1,J2))+YA(4)*(XL(K2,J2)-XL(K,J2)))/(XL(K2,J2)-XL(K1,J2))
     3  *(YL(K,J)-YL(K,J1)))/(YL(K,J2)-YL(K,J1))
      GO TO 400
390   DO 395 K=K1,K2
      DO 395 J=J1,J2
      LM=LVAR(K,J)
      AK1=AJ1=0.5
      IF (K1 .NE. K2) AK1=(K-K1)/(K2-K1)
      AK2=1.-AK1
      IF (J1 .NE. J2) AJ1=(J-J1)/(J2-J1)
      AJ2=1.-AJ1
      XD(LM)=(XA(1)*AK2+XA(2)*AK1)*AJ2+(XA(3)*AK1+XA(4)*AK2)*AJ1
395   YD(LM)=(YA(1)*AK2+YA(2)*AK1)*AJ2+(YA(3)*AK1+YA(4)*AK2)*AJ1
400   CONTINUE
C
C
C    CALL FOR ADDED DATA
450   IF (NEXTRA .GT. 0) CALL EXTRAT(2)
C ******* PRINT INITIAL LAYOUT
C
      PRINT 1250,DISCPT
      ZERO=0.
      DO 470 K=1,KMAX
      DO 460 J=1,JMAX
      LM=LVAR(K,J)
      IF (LM .LE. 0) GO TO 460
      IF (MM(K,J) .GT. 0) GO TO 455
      PRINT 1280,J,K,MM(K,J),LM,X(LM),Y(LM),ZERO,ZERO,ZERO,ZERO,XD(LM),
     1  YD(LM),ZERO
      GO TO 460
455   MAT=MM(K,J)
      YYY=0.
      IF (YC(MAT) .NE. 0) YYY=YY(LM)
      PRINT 1280,J,K,MAT,LM,X(LM),Y(LM),A(LM),D(LM),Z(LM),YYY,XD(LM),
     1  YD(LM),E(LM)
460   CONTINUE
470   CONTINUE
      RETURN
C
C ********INITIALIZE VALUES FROM A RESTART FILE
C
 500  NST= NSTART-1
      IF(NST .EQ. 0) GO TO 515
      DO 510 I=1,NST
      READ (1) A1
510   CONTINUE
 515  READ (1) (COM(I),I=1,JSIZE),(LVAR(I),I=1,JK),(MM(I),I=1,JK),JMAX,
     1  JMIN,KMAX,KMIN,TYME
C
C   CALL FOR ADDED DATA
      IF (NEXTRA .GT. 0) CALL EXTRAT(3)
      IF (KCHEK .EQ. 0) KCHEK=KMAX
      PRINT 1290
      DO 490 K=1,KMAX
      DO 480 J=1,JMAX
      LM=LVAR(K,J)
      IF(LM .LE. 0) GO TO 480
      PRINT 2000,K,J,P(LM),SXX(LM),SYY(LM),SZZ(LM),TXY(LM)
 1290 FORMAT(4X,1HK,4X,1HJ,9X,1HP,7X,3HSXX,7X,3HSYY,7X,3HSZZ,7X,3HTXY)
 2000 FORMAT(2I5,1P5E10.3)
 480  CONTINUE
 490  CONTINUE
      GO TO 450
C  ******       FORMATS       ******
C
 1000 FORMAT(1H1)
1001  FORMAT (43HOEOF ON INPUT, FOUND BY LAYOUTT, NORMAL END)
1002  FORMAT(1HO)
 1030 FORMAT (2A5,2I5,2A5,4F10.5,A5,A4,I1)
1031  FORMAT (2A5,2I5,2A5,4F10.2)
 1032 FORMAT (2A5,I10,2A5,I10,2A5,F10.3)
 1100 FORMAT(16A5)
 1104 FORMAT(4(2A5,E10.3))
 1105 FORMAT(8(A6,I4))
```

```
1106  FORMAT (8(A4,A3,I3))
 1107 FORMAT(2A5,7E10.3)
1108  FORMAT(2A5,E10.3,2A5,I10,2(2A5,I10))
1109  FORMAT (2A5,7A10)
 1110 FORMAT(2A5,7I10)
1111  FORMAT (8(A5,A3,I2))
1112  FORMAT(2A5,14I5/(16I5))
 1125 FORMAT(2A5,7(I6,2I2))
1130  FORMAT(6A5,E10.3,A5,A2,3I1,A5,A2,3I1,(A5,A3,I2,A5,A3,I2))
1250  FORMAT (1H1,20X,20A5//4X,*J*,4X,*K*,4X,*M*,* LVAR*,11X,*X*,11X,
     1  1HY,11X,1HA,11X,1HD,11X,1HZ,7X,5HYIELD,10X,2HXD,10X,2HYD,11X,
     2  1HE)
1280  FORMAT (4I5,5F12.6,1P4E12.3)
1133  FORMAT (2A5,2I5,2A5,2I5,2A5,I9,I1,2E10.4)
      END
```

SUBROUTINE REBAR

```
      SUBROUTINE REBAR(LL,IN,JC,IC,M,N,IH,DH,DOLD,SX,SY,SZ,TXY,E,P,
     1  DEX,DEY,DEZ,DEXY,F,THETA,DTHETA,ESC,FS,DSTL,SRS,
     2  ZEVP,TEVP,Y,ROLD,IPRINT)
C     SR1 AND SR3 ARE OLD AND NEW STRESSES ON STEEL.
C     SR2 AND SR4 ARE OLD AND NEW STRESSES ON CONCRETE.
C        ALL STRESSES ARE DEVIATORS EXCEPT SRS ARRAY
C        STRESSES ARE POSITIVE IN TENSION, PRESSURE IS POSITIVE IN COMP.
C        STRAINS ARE POSITIVE IN TENSION
C        PLANE OF REBARS IS INITIALLY NORMAL TO THE X DIRECTION
C        THETA IS OLD VALUE OF ROTATION ANGLE, POSITIVE TOWARDS Y
C        DTHETA IS INCREMENT OF THETA ON CURRENT CYCLE
      DIMENSION SR(4),SRS(4),SR1(4),SR2(4),DEC(4),DES(4),DE(4),SR3(4),
     1  SR4(4),THET(6),IMC(6),IMS(6),FSTEEL(6),ESC(6,20)
      IF (LL .GE. 0) GO TO 15
      READ 1004,A1,FSTEEL(M),A2,THET(M),A3,IMC(M),A4,IMS(M)
      PRINT 1004,A1,FSTEEL(M),A2,THET(M),A3,IMC(M),A4,IMS(M)
 1004 FORMAT(A10,E10.3,A10,E10.3,A10,I10,A10,I10)
      LS=0
      MC=IMC(M)
      MS=IMS(M)
      SX=SQRT((FSTEEL(M)*(ESC(MS,2)+1.33*ESC(MS,5))+(1.-FSTEEL(M))*
     1 (ESC(MC,2)+1.33*ESC(MC,5)))/(FSTEEL(M)*ESC(MS,1)+(1.-FSTEEL(M))*
     2 ESC(MC,1)))
      DH=FSTEEL(M)*ESC(MS,1)+(1.-FSTEEL(M))*ESC(MC,1)
      Y=ESC(MS,10)
      RETURN
15    IF( ROLD .NE. 0.) GO TO 18
      MC=IMC(M)
      MS=IMS(M)
      FS=FSTEEL(M)
      THETA=THET(M)
      DSTL=ESC(MS,1)
      ROLD=ESC(MC,1)
   18 CONTINUE
      MC=IMC(M) $ MS=IMS(M)
      NTRY=1
      RHOS=ESC(MC,7)
      EQSTC=ESC(MC,2)
      GRUN=ESC(MC,9)
      AMU=ESC(MC,5)
      CRIT=1.E7
      TEVPSV=TEVP
      ZEVPSV=ZEVP
      YSV=Y
      IHSV=IH
      IPRINT=0
      FS1=FS=(DOLD-ROLD)/(DSTL-ROLD)
      COS2TH=COS(2.*THETA)
      SIN2TH=SIN(2.*THETA)
C        ROTATE STRAIN INCREMENTS TO AXIS OF REBARS
      SIN2TH1=SIN2TH+DTHETA*COS2TH $ COS2TH1=COS2TH-SIN2TH*DTHETA
      DE(1)=(DEX+DEY+(DEX-DEY)*COS2TH1)/2.+DEXY*SIN2TH1
      DE(2)=(DEX+DEY-(DEX-DEY)*COS2TH1)/2.-DEXY*SIN2TH1
      DE(3)=DEZ
      DE(4)=-(DEX-DEY)*SIN2TH1/2.+DEXY*COS2TH1
C        ROTATE STRESSES TO AXIS OF REBARS
      SR(1)=(SX+SY+(SX-SY)*COS2TH)/2.+TXY*SIN2TH
      SR(2)=(SX+SY-(SX-SY)*COS2TH)/2.-TXY*SIN2TH
      SR(3)=SZ
      SR(4)=-(SX-SY)*SIN2TH/2.+TXY*COS2TH
      RL=0. $ RR=1.
      IF (IPRINT .EQ. 1) PRINT 1120,(SR(I),I=1,4),SX,SY,SZ,TXY,COS2TH,
     1  SIN2TH
C *******                                                    ***********
C        BEGINNING OF COMPUTATIONAL LOOP FOR EACH STRAIN INCREMENT
120   PS=PS1=-(SRS(1)+SRS(2)+SRS(3))/3.
      FS=FS1
      PC=PC1=(P-PS1*FS)/(1.-FS)
      DO 170 I=1,4
      SR1(I)=SRS(I)+PS1
      IF (I .EQ. 4) SR1(4)=SRS(4)
      SR2(I)=(SR(I)-SR1(I)*FS)/(1.-FS)
  170 DEC(I)=DES(I)=DE(I)*RR
      DES(1)=DEC(1)*ESC(MC,2)/ESC(MS,2)
```

```
      DEC(1)=(DE(1)*RR-DES(1)*FS)/(1.-FS)
  180 NC=0
C *******                                                    ***********
C        BEGINNING OF ITERATION LOOP
200   NC=NC+1
      DO 210 I=1,4
      SR3(I)=SR1(I)
  210 SR4(I)=SR2(I)
      TEVP=TEVPSV
      ZEVP=ZEVPSV
      Y=YSV
      IH=IHSV
      PS=PS1   $   PC=PC1
      RX=SR4(1)-PC $ RY=SR4(2)-PC $ RZ=SR4(3)-PC $ RXY=SR4(4)
      DEST=(DEC(1)+DEC(2)+DEC(3))/3.
      RH=ROLD*(2.-DEST)/(2.+DEST)
      IF (IPRINT .EQ. 1) PRINT 1002,RH,ROLD,RX,RY,RZ,RXY,ZEVP,TEVP
      CALL CAP1(LS,IN,MC,N,IH,RH,ROLD,E,DEC(1),DEC(2), DEC(3),DEC(4),
     1  RX,RY,RZ,RXY,ZEVP,IC,JC,TEVP)
      IF (IPRINT .EQ. 1) PRINT 1003,RH,ROLD,RX,RY,RZ,RXY,ZEVP,TEVP
      PC=-(RX+RY+RZ)/3.
      SR4(1)=RX+PC $ SR4(2)=RY+PC $ SR4(3)=RZ+PC $ SR4(4)=RXY
      DEST=(DES(1)+DES(2)+DES(3))/3.
      D=DSTL*(2.-DEST)/(2.+DEST)
      CALL EPLAS(JC,IC,MS,SR3,PS,DES,ESC,D,Y)
      SCTEST= SR4(1)-PC   $   SSTEST = SR3(1)-PS
      IF (IPRINT .EQ. 1) PRINT 1001,NC,DES(1),DEC(1),PC,PS,(SR1(I),I=1,4
     1  ),(SR2(I),I=1,4),(SR3(I),I=1,4),(SR4(I),I=1,4),SCTEST,SSTEST
      IF (ABS(SR4(1)-PC-SR3(1)+PS) .LT. CRIT) GO TO 290
      DEZA=DES(1)    $    DSZA=SR4(1)-SR3(1)   -PC+PS
      IF (NC .EQ. 1) GO TO 250
      IF (NC .LT. 12) GO TO 260
      IF (NTRY .LT. 5) GO TO 450
C        ABORT PROVISION
      PRINT 1240,JC,IC,N,PS,PC,SSTEST,SCTEST,SR1,SR2,SR3,SR4,DES,DEC
1240  FORMAT(1X,* ABORT IN REBAR FOR NTRY EQUALS 5 FOR J=*,I5,* I=*,I5,
     1 * ON CYCLE *,I5,/,1X,* PS=*,E10.3,* PC=*,E10.3,* SSTEST=*,E10.3,
     2 * SCTEST=*,E10.3/,* SR1=*,4E10.3,* SR2=*,4E10.3,/,* SR3=*,4E10.3,
     3 * SR4=*,4E10.3,/,* DES=*,4E10.3,* DEC=*,4E10.3)
      GO TO 320
C        PREPARATION FOR SECOND ITERATION
250   DES(1)=DES(1)+(SR4(1)-PC-SR3(1)+PS)/(ESC(MC,2)*FS/(1.-FS)+ESC(MS,2
     1  ))
      DEC(1)=(DE(1)*RR    -DES(1)*FS)/(1.-FS)
      GO TO 280
C        REGULA FALSI BRANCHES
260   IF (NC .EQ. 2) GO TO 262
      IF (DSZC .GT. 0.) GO TO 265
      IF (DSZB .LT. 0.) GO TO 262
      IF (DSZA .GT. 0.) GO TO 265
262   DES(1)=DEZA+(DEZB-DEZA)/(DSZB-DSZA)*(-DSZA)
      IF (NC .EQ. 6 .OR. NC .EQ. 10) DES(1)=0.5*(DEZA+DEZB)
      GO TO 270
265   DES(1)=DEZA+(DEZC-DEZA)/(DSZC-DSZA)*(-DSZA)
      IF (NC .EQ. 6 .OR. NC .EQ. 10) DES(1)=0.5*(DEZA+DEZC)
270   DEC(1)=(DE(1)*RR    -DES(1)*FS)/(1.-FS)
      IF (NC .GT. 2) GO TO 275
      IF (DSZA .LT. DSZB) 283,279
275   IF (DSZA .GT. DSZB .OR. DSZA .LT. DSZC) GO TO 277
      IF (DSZA .LT. 0.) 283,280
277   IF (DSZB .LT. 0. .AND. DSZA .GT. DSZB) GO TO 279
      IF (DSZC .GT. 0. .AND. DSZA .GT. DSZC) 282,200
279   DSZC=DSZB    $    DEZC=DEZB
280   DSZB=DSZA    $    DEZB=DEZA    $    GO TO 200
282   DSZB=DSZC    $    DEZB=DEZC
283   DSZC=DSZA    $    DEZC=DEZA    $    GO TO 200
C *******                                                    ***********
C        END OF ITERATION LOOP, RESET FOR NEXT STRAIN INCREMENT
290   DO 295 I=1,4
      SR1(I)=SR3(I)
295   SR2(I)=SR4(I)
      IHSV=IH
      YSV=Y
      TEVPSV=TEVP
      ZEVPSV=ZEVP
```

SUBROUTINE REBAR (Concluded)

```
      FS=FS*(1.+DES(1))/(FS*(1.+DES(1))+(1.-FS)*(1.+DEC(1)))
      DSTL=D
      ROLD=RH
      PS1=PS   $   PC1=PC
      RL=RL+RR
      IF (RL .LT. .999) GO TO 180
C        ENDING ROUTINE
320   CONTINUE
      DO 330 I=1,4
      SR(I)=SR4(I)*(1.-FS)+SR3(I)*FS
330   SRS(I)=SR3(I)-PS
      SRS(4)=SR3(4)
      THETA2=(THETA+DTHETA)*2.
      SIN2TH1=SIN(THETA2) $ COS2TH1=COS(THETA2)
      SX=(SR(1)+SR(2)+(SR(1)-SR(2))*COS2TH1)/2.-SR(4)*SIN2TH1
      SY=(SR(1)+SR(2)-(SR(1)-SR(2))*COS2TH1)/2.+SR(4)*SIN2TH1
      SZ=SR(3)
      TXY=+(SR(1)-SR(2))/2.*SIN2TH1+SR(4)*COS2TH1
      IF (IPRINT .EQ. 1) PRINT 1120,(SR(I),I=1,4),SX,SY,SZ,TXY,COS2TH1,
     1  SIN2TH1
      P=PC*(1.-FS)+PS*FS
      RETURN
C        PROVISION TO CUT STRAIN INCREMENTS
450   NTRY=NTRY+1
      IF (NTRY .EQ. 5) IPRINT=1
      RR=RR/3.
      GO TO 120
1001  FORMAT(1X,* NC=*I5,* DES(1),DEC(1)=*, 1P2E10.3,* PC=*,E10.3,* PS=*
     1,E10.3,/,1X,* SR1=*,4E10.3,* SR2=*,4E10.3,/,1X,* SR3=*,4E10.3,
     2* SR4=*,4E10.3/,1X,* (CONCRETE STRESS) SR4(1)-PC=*,E12.5,* (STEEL
     3STRESS) SR3(1)-PS=*,E12.5)
1002  FORMAT(* BEFORE CAP,RH,ROLD=*1P2E10.3,
     1  * RX,RY,RZ,RXY=*4E10.3,* ZEVP,TEVP=*2E10.3)
1003  FORMAT (* AFTER CAP, RH,ROLD=*1P2E10.3,
     1  * RX,RY,RZ,RXY=*4E10.3,* ZEVP,TEVP=*2E10.3)
1120  FORMAT(* SR1,SR2,SR3,SR4=*4E10.3/* SX,SY,SZ,TXY=*4E10.3/* COS2TH,
     1  SIN2TH=*2E10.3)
      END
```

SUBROUTINE SCRIBET

```
      SUBROUTINE SCRIBET                                                SCRIBET
      COMMON/NSCRB/SJ(60),NJED,NJKED,NKED,N,TIMEZ,DISCPT(20),JEDJ(60),  NSCRBCOM
     1 JEDK(60),JEDT(60),NAME(60)                                       NSCRBCOM
      DIMENSION R(1)                                                    SCRIBET
      EQUIVALENCE (R,SJ)                                                SCRIBET
      REWIND 4                                                          SCRIBET
      READ (4) A1                                                       SCRIBET
      NSCRIBE=N1=1                                                      SCRIBET
      N2=MIN0(N1+7,NJKED)                                               SCRIBET
      DO 30 NP=1,N                                                      SCRIBET
      READ (4) NN,T,DT,DELTIM,(R(I), I=1,NJKED)                         SCRIBET
      IF (MOD(NN,50) .EQ. 1) PRINT 1001, DISCPT,NSCRIBE,(JEDT(I),       SCRIBET
     1    JEDK(I),JEDJ(I), I=N1,N2)                                     SCRIBET
      PRINT 1100, NN,T,DT,DELTIM,(R(I), I=N1,N2)                        SCRIBET
   30 CONTINUE                                                          SCRIBET
      GO TO 120                                                         SCRIBET
   50 N2=MIN0(N1+9,NJKED)                                               SCRIBET
      READ (4) A1                                                       SCRIBET
      DO 100  NP=1,N                                                    SCRIBET
      READ (4) NN,T,DT,DELTIM,(R(I), I=1,NJKED)                         SCRIBET
      IF (MOD(NN,50) .EQ. 1) PRINT 1000,DISCPT,NSCRIBE,(JEDT(I),JEDK(I), SCRIBET
     1  JEDJ(I),I=N1,N2)                                                SCRIBET
      PRINT 1100, NN,T,(R(I),I=N1,N2)                                   SCRIBET
  100 CONTINUE                                                          SCRIBET
  120 REWIND 4                                                          SCRIBET
      N1=N2+1                                                           SCRIBET
      NSCRIBE=NSCRIBE+1                                                 SCRIBET
      IF (N2 .LT. NJKED)  GO TO 50                                      SCRIBET
      CALL SECOND(TIMNOW)                                               SCRIBET
      CALTIM=TIMNOW-TIMEZ                                               SCRIBET
      PRINT 1200, CALTIM                                                SCRIBET
      RETURN                                                            SCRIBET
 1000 FORMAT (1H1,20A5,/9H NSCRIBE=I3,31H, HISTORIES, TIME IN MUSEC, STR SCRIBET
     1  51HESS IN DYN/CM2, VELOCITY IN CM/SEC,DENSITY IN G/CM3//4X,1HN, SCRIBET
     2  7X,4HTIME,10(1X,A3,1H(I2,1H,I2,1H))/)                           SCRIBET
 1001 FORMAT(1H1,20A5/9H NSCRIBE=I3,31H, HISTORIES, TIME IN MUSEC, STR  SCRIBET
     1  51HESS IN DYN/CM2, VELOCITY IN CM/SEC,DENSITY IN G/CM3//4X,1HN, SCRIBET
     2  7X,4HTIME,9X,2HDT,5X,6HDELTIM,8(1X,A3,1H(I2,1H,I2,1H))/)        SCRIBET
 1100 FORMAT(I5,1PE11.3,10E11.3)                                        SCRIBET
 1200 FORMAT(* CALTIM=*F8.3,* SEC*)                                     SCRIBET
      END                                                               SCRIBET
```

```
      SUBROUTINE SWEEPT(JSIZE,JXX,KXX,XL,YL,MM,IZ,LVAR)                  SWEEPT     2
C                                                                        SWEEPT     3
C     ROUTINE PERFORMS COMPUTATIONS FOR EACH CELL AT EACH CYCLE.         SWEEPT     4
C     COMPUTATIONS ARE MADE FOR VELOCITY (FROM MOMENTUM CONSERVATION),   SWEEPT     5
C     STRAIN AND DENSITY CHANGES (MASS CONSERVATION), ENERGY (ENERGY     SWEEPT     6
C     CONSERVATION) AND STRESS (CONSTITUTIVE EQUATIONS AND EQUATIONS OF  SWEEPT     7
C     STATE).                                                            SWEEPT     8
C     SELECTED VALUES ARE STORED FOR HISTORIES.                          SWEEPT     9
C        STRESSES ARE POSITIVE IN TENSION, PRESSURE POSITIVE IN COMP     SWEEPT    10
C        SXX, ETC ARE DEVIATORS,  TXX, ETC ARE TOTAL STRESSES            SWEEPT    11
C                                                                        SWEEPT    12
      COMMON/EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6),  EQSCOM     2
     1  EQSTS(6),RHO(6),RHOS(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,  EQSCOM     3
     2  TRIQ,AMAT(6,4),SP(6),G2(6),PMIN(6)                               EQSCOM     4
      COMMON/NSCRB/SJ(60),NJED,NJKED,NKED,N,TIMEZ,DISCPT(20),JEDJ(60),   NSCRBCOM   2
     1  JEDK(60),JEDT(60),NAME(60)                                       NSCRBCOM   3
      COMMON/GEN/LZ(1),IJBUND,       JMAX,JMIN,KMAX,KMIN,UZERO,CALTIM,   TROTTCOM   2
     1   DELTIM,DT,DTN,TS,TYME,NSTART,NPLOT,NDUMP,IMAX,IPRINT            TROTTCOM   3
     2  ,KSKIP,KFULL,KPMAX,KPMIN,JPMAX,JPMIN,JSLIDE,KSLIDE               TROTTCOM   4
     3  ,NSCRIB,DTW,NEXED,NOBLQ,TANTH,JPRINT,JPR,JP1(20),JP2(20),KCHEK   TROTTCOM   5
     4  ,NBND,IBDJ1(6),IBDJ2(6),IBDK1(6),IBDK2(6),IBDX(6),IBDY(6),       TROTTCOM   6
     5   XFIX(6),YFIX(6)                                                 TROTTCOM   7
      COMMON/CAL/ LISTE,LISTS,LISTX,LISTXD,CALE,CALS,CALX,CALXD          TROTTCOM   8
      COMMON/IND/NCMP(6),NFR(6),NPOR(6),NDS(6),NPR(6),NVAR(6),NTRI(6)    TROTTCOM   9
      COMMON/TSR/TSR(6,21),BFR(6,20)                                     TROTTCOM  10
      COMMON/T/COM(1000)                                                 SWEEPT    16
      DIMENSION XA(4),YA(4),XL(KXX,JXX),YL(KXX,JXX),MM(KXX,JXX),IZ(KXX,  SWEEPT    17
     1 JXX),LVAR(KXX,JXX)                                                SWEEPT    18
      REAL MU                                                            SWEEPT    19
      DIMENSION X(1),Y(1),XD(1),YD(1),M(1),A(1),Z(1),D(1),SXX(1),SYY(1), SWEEPT    20
     1  SZZ(1),TXY(1),TXX(1),TYY(1),TZZ(1),P(1),E(1),TH(1),FS(1),DSTL(1) SWEEPT    21
     2  ,SRS(1),ZEVP(1),TEVP(1),YY(1),ROLD(1),IH(1),ENM(1),ENT(1),       SWEEPT    22
     3  ICOM(1),CLB(1),CL1(1),CN(1),FF(1)                                SWEEPT    23
      EQUIVALENCE (COM,ICOM),(COM(1), X),(COM(2),Y),(COM(3),XD),         SWEEPT    24
     1  (COM(4),YD),(COM(5),M),(COM(6),A),(COM(7),Z),(COM(8),D),(COM(9), SWEEPT    25
     2  SXX),(COM(10),SYY),(COM(11),SZZ),(COM(12),TXY),(COM(13),TXX),    SWEEPT    26
     3  (COM(14),TYY),(COM(15),TZZ),(COM(16),P),(COM(17),E),(COM(18),    SWEEPT    27
     4  IH),(COM(19),YY),(COM(20),TH),(COM(21),ZEVP),(COM(22),TEVP),     SWEEPT    28
     5  (COM(23),FS),(COM(24),DSTL),(COM(25),ROLD),(COM(26),SRS),        SWEEPT    29
     6  (COM(22),ENM),(COM(23),ENT),(COM(23),CLB),(COM(28),CL1),(COM(33) SWEEPT    30
     7  ,CN),(COM(21),FF)                                                SWEEPT    31
      DIMENSION XTEMP(100),YTEMP(100),XDTEMP(100),YDTEMP(100),LCON(100)  SWEEPT    32
      DATA LCON/100*0/                                                   SWEEPT    33
      JE=1                                                               SWEEPT    34
      F=1.                                                               SWEEPT    35
      IF (N .EQ. 1) LSFRACT=0                                            SWEEPT    36
      IF (N .EQ. 1) SINTH=SIN(NOBLQ/57.2957795)                          SWEEPT    37
      IF (N .EQ. 1) COSTH=COS(NOBLQ/57.2957795)                          SWEEPT    38
      IF (N .EQ. 1) LCON(1)=1                                            SWEEPT    39
      IHEAD=1                                                            SWEEPT    40
      IPR=0                                                              SWEEPT    41
      IF (MOD(N,IPRINT) .EQ. 0) GO TO 100                                SWEEPT    42
      IF (JPRINT .EQ. 0) GO TO 110                                       SWEEPT    43
      IF (N .LT. JP1(JPR) .OR. N .GT. JP2(JPR)) GO TO 110                SWEEPT    44
  100 IHEAD=2                                                            SWEEPT    45
  110 CONTINUE                                                           SWEEPT    46
      DTSQM=1.                                                           SWEEPT    47
      DO 950   K=1,KMAX                                                  SWEEPT    48
      KHEAD=2                                                            SWEEPT    49
      DO 920   J=1,JMAX                                                  SWEEPT    50
       LVARM=LVAR(K,J)                                                   SWEEPT    51
      IF (LVARM .LE. 0) GO TO 780                                        SWEEPT    52
      DW=0.                                                              SWEEPT    53
      TXXW=0.                                                            SWEEPT    54
      TYYW=0.                                                            SWEEPT    55
      TZZW=0.                                                            SWEEPT    56
      TXYW=0.                                                            SWEEPT    57
      SXXW=0.                                                            SWEEPT    58
      SYYW=0.                                                            SWEEPT    59
      SZZW=0.                                                            SWEEPT    60
      EW=0.                                                              SWEEPT    61
      PW=0.                                                              SWEEPT    62
      Q=0.                                                               SWEEPT    63
      SPSQ=0.                                                            SWEEPT    64
```

```
C *****************                                  *********************
C                      BEGIN MOMENTUM CALCULATIONS
C *****************                                  *********************
      XDNH=XD(LVARM)
      YDNH=YD(LVARM)
      FX=0.
      FY=0.
      XMOM=0.
      AMASS=0.
      L3=LVARM
C
C *******     FIND COORDINATES OF CELLS AROUND POINT  (K,J)
C
      DO 360  I=1,4
      ITRI=0
      DMASS=0.
      GO TO (230,240,250,260) I
C
C  XXXX   I=1,  UPPER RIGHT HAND QUADRANT   XXXX
 230  IF(K .EQ. KMAX .OR. J .EQ. JMAX)GO TO 360
      IF (J .EQ. JSLIDE-1) GO TO 360
      IF (K .EQ. KSLIDE-1) GO TO 235
      IF (MM(K+1,J+1) .LE. 0) GO TO 360
      L1=LVAR(K+1,J+1)
      L2=LVAR(K,J+1)
      L4=LVAR(K+1,J)
      LM=L1
      MAT=MM(K+1,J+1)
      GO TO 270
C       K-SLIDE CASE
235   IF (LCON(J) .EQ. 0) GO TO 360
      L4=L3
      L1=L2=LVAR(K,J+1)
      GO TO 262
C
C   XXXX   I=2,   UPPER LEFT HAND QUADRANT   XXXX
 240  IF(K .EQ. 1 .OR. J .EQ. JMAX)GO TO 360
      IF (J .EQ. JSLIDE-1) GO TO 360
      IF (K .EQ. KSLIDE) GO TO 360
      IF (MM(K,J+1) .LE. 0) GO TO 360
      L1=LVAR(K-1,J+1)
      L2=LVAR(K-1,J)
      L4=LVAR(K,J+1)
      LM=L4
      MAT=MM(K,J+1)
      IF (K .EQ. KSLIDE-1) XMOM=XMOM+0.25*Z(LM)*XD(L3)
      GO TO 270
C
C   XXXX   I=3,  LOWER LEFT QUADRANT
 250  IF(K .EQ. 1 .OR. J .EQ. 1) GO TO 360
      IF (J .EQ. JSLIDE) GO TO 255
      IF (K .EQ. KSLIDE) GO TO 360
      IF (MM(K,J) .LE. 0) GO TO 360
      L1=LVAR(K-1,J-1)
      L2=LVAR(K,J-1)
      L4=LVAR(K-1,J)
      LM=L3
      MAT=MM(K,J)
      IF (K .EQ. KSLIDE-1) XMOM=XMOM+0.25*Z(LM)*XD(L3)
      GO TO 270
C       J-SLIDE CASE
255   L2=L3
      L1=L4=LVAR(K-1,J)
      XSTAR=0.75*X(L3)+0.25*X(L4)
      GO TO 267
C
C   ****   I=4, LOWER RIGHT QUADRANT
 260  IF(K .EQ. KMAX .OR. J .EQ. 1)GO TO 360
      IF (J .EQ. JSLIDE) GO TO 265
      IF (K .EQ. KSLIDE-1) GO TO 262
      IF (MM(K+1,J) .LE. 0) GO TO 360
      L1=LVAR(K+1,J-1)
      L2=LVAR(K+1,J)
      L4=LVAR(K,J-1)
      LM=L2
```

SUBROUTINE SWEEPT (Continued)

```
      MAT=MM(K+1,J)
      GO TO 270
C        K-SLIDE CASE
262   IF (LCON(J) .EQ. 0) GO TO 360
      L2=L3
      L1=L4=LVAR(K,J-1)
      JS=LCON(J)
      LX=LVAR(KSLIDE,JS)
      IF (JS .EQ. 1) JS=2
      LM=LVAR(KSLIDE+1,JS)
      DMASS=0.25*Z(LM)
      XMOM=XMOM+XD(LX)*DMASS
      GO TO 270
C        J-SLIDE CASE
265   L4=L3
      L1=L2=LVAR(K+1,J)
      XSTAR=0.75*X(L3)+0.25*X(L2)
267   L=LVAR(1,JSLIDE-1)
      IF (XSTAR .LT. X(L)) GO TO 360
      KS=1
268   KS=KS+1
      IF (KS .GE. KMAX) GO TO 360
      L=LVAR(KS,JSLIDE-1)
      IF (L .LT. 0) GO TO 360
      IF (XSTAR .GT. X(L)) GO TO 268
      LM=L
      DMASS=0.25*Z(LM)
      XMOM=XMOM+XD(LM)*DMASS
      GO TO 300
C *****************                                        ********************
C             COMPUTE AREAS, MASSES, FORCES ACTING ON COORDINATE (K,J)
C *****************                                        ********************
270   IF (M(LM) .EQ. 0) GO TO 300
      LMS=LM
C
C *******     TRIANGULAR CELLS
      QXX=QYY=QXY=0.
      IF (I .EQ. 2 .OR. I .EQ. 4) GO TO 275
      ITRI=-1
      XO2=X(L2)+X(L4)
      YO2=Y(L2)+Y(L4)
      IF (I .EQ. 1) LM=M(LM)
      GO TO 305
C
C     TRIANGULAR CELL WITH POINTS 1,3,4
275   ITRI=1
      AXY=(X(L4)*(Y(L1)-Y(L3))+X(L3)*(Y(L4)-Y(L1))+X(L1)*(Y(L3)-Y(L4)))
     1 /8.
      A3=4.*AXY
      IF (I .EQ. 4) LM=M(LMS)
      IF (IJBUND .GT. 0) GO TO 280
      AXX=(Y(L1)-Y(L4))/2.
      AYY=(X(L4)-X(L1))/2.
      TZZAXY=0.
      IF (DMASS .NE. 0.) GO TO 330
      DMASS=D(LM)*AXY
      GO TO 330
280   AXX=(Y(L1)-Y(L4))*(Y(L1)+2.*Y(L3)+Y(L4))/8.
      AYY=(X(L4)-X(L1))*(Y(L1)+2.*Y(L3)+Y(L4))/8.
      TZZAXY=TZZ(LM)*AXY
      IF (DMASS .NE. 0.) GO TO 330
      DMASS=D(LM)*AXY*(0.666667*Y(L3)+(Y(L1)+Y(L4))/6.)
      GO TO 330
C
C     TRIANGULAR CELL WITH POINTS 1,2,3
285   ITRI=2
      AXY=(X(L1)*(Y(L2)-Y(L3))+X(L2)*(Y(L3)-Y(L1))+X(L3)*(Y(L1)-Y(L2)))
     1 /8.
      A3=4.*AXY
      LM=LMS
      IF (I .EQ. 2) LM=M(LMS)
      IF (IJBUND .GT. 0) GO TO 290
      AXX=(Y(L2)-Y(L1))/2.
      AYY=(X(L1)-X(L2))/2.
      TZZAXY=0.
```

```
      DMASS=D(LM)*AXY
      GO TO 330
290   AXX=(Y(L2)-Y(L1))*(Y(L2)+2.*Y(L3)+Y(L1))/8.
      AYY=(X(L1)-X(L2))*(Y(L2)+2.*Y(L3)+Y(L1))/8.
      TZZAXY=TZZ(LM)*AXY
      DMASS=D(LM)*AXY*(0.666667*Y(L3)+(Y(L1)+Y(L2))/6.)
      GO TO 330
C
C *******     QUADRILATERAL CELLS
300   X02=0.5*(X(L1)+X(L2)+X(L3)+X(L4))
      Y02=0.5*(Y(L1)+Y(L2)+Y(L3)+Y(L4))
305   A0=(X02-X(L3))*(Y(L2)-Y(L4))+X(L2)*(Y(L3)+Y(L4)-Y02)+X(L4)
     - *(Y02-Y(L2)-Y(L3))
      A3=X(L4)*(Y(L2)-Y(L3))-X(L3)*(Y(L2)-Y(L4))+X(L2)*(Y(L3)-Y(L4))
      AXY=(A0+A3)/8.
      IF (IJBUND .GT. 0) GO TO 320
      AXX=(Y(L2)-Y(L4))/2.
      AYY=(X(L4)-X(L2))/2.
      TZZAXY=0.
      IF (DMASS .NE. 0.) GO TO 330
      DMASS=D(LM)*AXY
      GO TO 330
320   AXX=(Y(L2)-Y(L4))*(Y(L2)+2.*Y(L3)+Y(L4))/8.
      AYY=((Y(L2)-Y(L4))*(X02-X(L3))+(X(L4)-X(L2))*(Y02+Y(L3))-X(L2)*
     1  Y(L2)+X(L4)*Y(L4))/8.
      IF (DMASS .NE. 0.) GO TO 330
      DMASS=D(LM)*(A0*((Y(L2)+Y(L4)+Y02)/2.+Y(L3))+A3*((Y(L2)+Y(L4))/
     -  2.+2.*Y(L3)))/24.
      TZZAXY=TZZ(LM)*AXY
C        STRAINS EDXX, EDYY, AND EDXY ARE POSITIVE IN TENSION
 330  QXX=QYY=QXY=0.
      IF (J .EQ. JSLIDE .AND. (I.EQ.3 .OR. I.EQ.4)) GO TO 340
      IF (K .EQ. KSLIDE-1 .AND. (I .EQ. 1 .OR. I .EQ. 4)) GO TO 340
      IF (TRIQ .EQ. 0. .OR. A3 .LT. 0.1*AXY) GO TO 340
      EDXX=((XD(L2)-XD(L3))*(Y(L2)-Y(L4))-(XD(L2)-XD(L4))*(Y(L2)-
     1  Y(L3)))/A3
      EDYY=-((YD(L2)-YD(L3))*(X(L2)-X(L4))-(YD(L2)-YD(L4))*(X(L2)-
     -  X(L3)))/A3
      EDXY=(-(XD(L2)-XD(L3))*(X(L2)-X(L4))+(XD(L2)-XD(L4))*(X(L2)-
     1  X(L3))+(YD(L2)-YD(L3))*(Y(L2)-Y(L4))-(YD(L2)-YD(L4))*(Y(L2)-
     2  Y(L3)))/A3
C        TRIANGLE Q STRESSES QXX, QYY, AND QXY ARE POSITIVE IN TENSION
      COEF=SQRT(A3)*SP(MAT)*D(LM)*TRIQ
      QXX=COEF*(2.*EDXX-EDYY)
      QYY=COEF*(2.*EDYY-EDXX)
      QXY=3.*COEF*EDXY
340   FX=FX+(TXX(LM)+QXX)*AXX+(TXY(LM)+QXY)*AYY
      FY=FY+(TXY(LM)+QXY)*AXX+(TYY(LM)+QYY)*AYY-TZZAXY
      AMASS=AMASS+DMASS
      IF (ITRI .EQ. 1) GO TO 285
360   CONTINUE
C
C  ****   COMPUTE POSITIONS AND VELOCITIES AT -K,J-
C
      LM=LVAR(K,J)
      IJBABS=IABS(IJBUND)
      IF (IJBABS .NE. 9) GO TO 344
      IB=0
      DO 342 NB=1,NBND
      IF (J .LT. IBDJ1(NB) .OR. J .GT. IBDJ2(NB)) GO TO 342
      IF (K .LT. IBDK1(NB) .OR. K .GT. IBDK2(NB)) GO TO 342
      IF (IBDY(NB) .EQ. 0) GO TO 345
      IF (IBDY(NB) .LE. 1) GO TO 347
      IB=NB
      GO TO 345
342   CONTINUE
      GO TO 345
344   IF (J .EQ. JMAX .AND. (IJBABS.EQ.1 .OR. IJBABS.EQ.5)) GO TO 347
      IF (J .EQ. 1 .AND. IJBUND .NE. -3) GO TO 347
      IF (IJBUND .EQ. 2 .AND. Y(LM) .EQ. 0.) GO TO 347
345   YDNH=YD(LM)+DTN*FY/AMASS
347   YNW=Y(LM)+YDNH*DT
      IF (IB .EQ. 0) GO TO 349
      IF (IBDY(IB) .EQ. 2) YNW=AMIN1(YNW,YFIX(IB))
      IF (IBDY(IB) .EQ. 3) YNW=AMAX1(YNW,YFIX(IB))
```

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349   IF (IJBUND .GT. 0) YNW=AMAX1(YNW,0.)
      YDNH=(YNW-Y(LM))/DT
      IF (IJBABS .NE. 9) GO TO 354
      IB=0
      DO 352 NB=1,NBND
      IF (J .LT. IBDJ1(NB) .OR. J .GT. IBDJ2(NB)) GO TO 352
      IF (K .LT. IBDK1(NB) .OR. K .GT. IBDK2(NB)) GO TO 352
      IF (IBDX(NB) .EQ. 0) GO TO 356
      IF (IBDX(NB) .LE. 1) GO TO 357
      IB=NB
      GO TO 356
352   CONTINUE
      GO TO 356
354   IF (K .EQ. 1 .AND. (IJBABS .EQ. 4 .OR. IJBABS .EQ. 5 .OR.
     1  IJBABS .EQ. 6)) GO TO 357
      IF (K .EQ. KMAX .AND. IJBABS .EQ. 4) GO TO 357
356   XDNH=XD(LM)+DTN*FX/AMASS
357   IF (K .EQ. KSLIDE-1 .AND. LCON(J) .NE. 0) XDNH=XMOM/AMASS+DTN*FX/
     1  AMASS
      XNW=X(LM)+XDNH*DT
      IF (IB .EQ. 0) GO TO 362
      IF (IBDX(IB) .EQ. 2) XNW=AMIN1(XNW,XFIX(IB))
      IF (IBDX(IB) .EQ. 3) XNW=AMAX1(XNW,XFIX(IB))
362   CONTINUE
C
C     ADJUST XNW AND XDNH FOR SLIDE LINE
C     (CALC ON KSLIDE-1, ADJUST KSLIDE)
      IF (K .NE. KSLIDE) GO TO 375
      JS=1
      LMR=LVAR(KSLIDE-1,JS)
      IF (YNW .GT. Y(LMR)) GO TO 355
      IF (J .GE. JMAX) GO TO 355
      LMJ1=LVAR(K,J+1)
      IF (LMJ1 .LE. 0) GO TO 355
      IF (Y(LMJ1) .LT. Y(LMR)) GO TO 370
355   JS=JS+1
      IF (JS .EQ. JMAX+1) GO TO 365
      LMRT=LVAR(KSLIDE-1,JS)
      IF (LMRT .LE. 0) GO TO 365
      LML=LMR
      LMR=LMRT
      IF (YNW .GT. Y(LMR)) GO TO 355
358   XCONT=X(LML)+(YNW-Y(LML))*(X(LMR)-X(LML))/(Y(LMR)-Y(LML))
      IF (XNW .GT. XCONT+0.001) GO TO 370
      XNW=XCONT
      IF (LCON(JS) .NE. 0) XDNH=XD(LML)+(YNW-Y(LML))*(XD(LMR)-XD(LML))/
     1  (Y(LMR)-Y(LML))
      LCON(JS)=J
      GO TO 375
365   IF (J .EQ. 1) GO TO 375
      LMJ=LVAR(K,J-1)
      IF (Y(LMJ) .LE. Y(LMR)) GO TO 358
      GO TO 375
370   LCON(J)=0
375   CONTINUE
C
C *******     ADJUST YNW AND YDNH FOR SLIDE LINE
      IF (J .NE. JSLIDE-1) GO TO 394
      KS=1
      LMR=LVAR(KS,JSLIDE)
      IF (XNW .GT. X(LMR)) GO TO 380
      IF (K .GE. KMAX) GO TO 380
      LMJ1=LVAR(K+1,J)
      IF (LMJ1 .LE. 0) GO TO 380
      IF (X(LMJ1) .LT. X(LMR)) GO TO 394
      YCONT=Y(LMR)+(XNW-X(LMR))*(Y(LMJ1)-Y(LMR))/(X(LMJ1)-X(LMR))
      IF (YNW .LT. YCONT) GO TO 394
      YNW=YCONT
      YDNH=YD(LMR)+(XNW-X(LMR))*(YD(LMJ1)-YD(LMR))/(X(LMJ1)-X(LMR))
      GO TO 394
380   KS=KS+1
      IF (KS .EQ. KMAX+1) GO TO 386
      LMRT=LVAR(KS,JSLIDE)
      IF (LMRT .LE. 0) GO TO 386
      LML=LMR
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      LMR=LMRT
      IF (XNW .GT. X(LMR)) GO TO 380
 383  YCONT=Y(LML)+(XNW-X(LML))*(Y(LMR)-Y(LML))/(X(LMR)-X(LML))
      IF (YNW .LT. YCONT) GO TO 394
      YNW=YCONT
      YDNH=YD(LML)+(XNW-X(LML))*(YD(LMR)-YD(LML))/(X(LMR)-X(LML))
      PRINT 1394,N,K,J,YNW,YDNH
 1394 FORMAT(*  N =*I3,* K,J =*2I3,*  YNW,YDNH=*2F13.6)
      GO TO 394
 386  IF (K .EQ. 1) GO TO 394
      LMJ=LVAR(K-1,J)
      IF (X(LMJ) .LE. X(LMR)) GO TO 383
C
C ********    ADJUST XNW, YNW FOR OBLIQUE IMPACT ON FIXED PLANE
 394  CONTINUE
      IF (NOBLQ .EQ. 0) GO TO 396
      IF (K .NE. KMAX .AND. J .NE. 1) GO TO 396
      LL=LVAR(KMAX,1)
      IF (XNW .LT. X(LL)+(YNW-Y(LL))*TANTH) GO TO 396
      IF (XDNH .EQ. 0. .AND. YDNH .EQ. 0.) GO TO 396
      DDT=(X(LL)-X(LM)+(Y(LM)-Y(LL))*TANTH)/(XDNH-YDNH*TANTH)
      XNW=X(LM)+XDNH*DDT
      YNW=Y(LM)+YDNH*DDT
      DTI=(XNW-X(LM))/XDNH
      VT=XDNH*SINTH+YDNH*COSTH
      XDNH=VT*SINTH
      YDNH=VT*COSTH
      XNW=XNW+XDNH*(DT-DTI)
      YNW=YNW+YDNH*(DT-DTI)
 396  CONTINUE
      IF (MM(K,J) .EQ. 0) GO TO 750
C
C     ****   COMPUTE NEW AREA  AND VOLUME FOR CELL  -K,J-
C
      A124=XTEMP(J-1)*(YNW-YTEMP(J))-XNW*(YTEMP(J-1)-YTEMP(J))+
     1  XTEMP(J)*(YTEMP(J-1)-YNW)
      LM=LVAR(K,J)
      LMM=LVAR(K-1,J-1)
      LKM=LVAR(K,J-1)
      LMJ=LVAR(K-1,J)
      A234=XTEMP(J-1)*(YTEMP(J)-YKMJM)+XTEMP(J)*(YKMJM-YTEMP(J-1))+
     1  XKMJM*(YTEMP(J-1)-YTEMP(J))
      ITRI=0
      IF (M(LM) .EQ. 0) GO TO 420
      LMS=LM
      ITRI=1
C     TRIANGLE WITH POINTS 1,2,4
      AW=A124/2.
      IF (AW.GT.0.) GO TO 400
      IF (AW .LE. 0.) PRINT 93,K,J,A124,A234,XNW,XTEMP(J),XTEMP(J-1),
     1  XKMJM,YNW,YTEMP(J),YTEMP(J-1),YKMJM
 93   FORMAT(* POINTS 124  K,J=*2I3,* A124,A234=*1P2E10.3,* XNW,XTEMP(J)
     1,XTEMP(J-1)=*3E10.3/* XKMJM,YNW,YTEMP(J)=*1P3E10.3,* YTEMP(J-1),*
     2  *YKMJM=*2E10.3)
      NSCRIB = 1
      GO TO 920
  400 CONTINUE
      DW=Z(LM)/AW
      IF (IJBUND .GT. 0) DW=2.*Z(LM)/(A124*(YTEMP(J-1)+YNW+YTEMP(J)))
      DTA=DT/(AW+A(LM))
      YH12=(Y(LM)+YNW-YTEMP(J)-Y(LMJ))/2.
      YH14=(Y(LM)+YNW-YTEMP(J-1)-Y(LKM))/2.
      XDH12=XDNH-XDTEMP(J)
      XDH14=XDNH-XDTEMP(J-1)
      XH12=(X(LM)+XNW-XTEMP(J)-X(LMJ))/2.
      XH14=(X(LM)+XNW-XTEMP(J-1)-X(LKM))/2.
      YDH12=YDNH-YDTEMP(J)
      YDH14=YDNH-YDTEMP(J-1)
      DELX=A124**2/(AMAX1(XH12**2+YH12**2,XH14**2+YH14**2,(XTEMP(J)-
     1  XTEMP(J-1))**2+(YTEMP(J)-YTEMP(J-1))**2))
      EVOL=2.*(D(LM)-DW)/(D(LM)+DW)
      EXXH=DTA*(XDH12*YH14-XDH14*YH12)
      EYYH=DTA*(YDH14*XH12-YDH12*XH14)
      EXYH=DTA*(XDH14*XH12-XDH12*XH14+YDH12*YH14-YDH14*YH12)/2.
      EZZH=EVOL-EXXH-EYYH
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C     CLOCKWISE ROTATION
      ALFA=DTA*(XDH12*XH14-XDH14*XH12+YDH12*YH14-YDH14*YH12)/2.
      GO TO 430
C     TRIANGLE WITH POINTS 2,3,4
405   ITRI=2
      LM=M(LMS)
      AW=A234/2.
      IF (AW.GT.O.) GO TO 410
      IF (AW .LE. O.) PRINT 94,K,J,A124,A234,XNW,XTEMP(J),XTEMP(J-1),
     1  XKMJM,YNW,YTEMP(J),YTEMP(J-1),YKMJM
94    FORMAT(* POINTS 234  K,J=*2I3,* A124,A234=*1P2E10.3,* XNW,XTEMP(J)
     1,XTEMP(J-1)=*3E10.3/* XKMJM,YNW,YTEMP(J)=*1P3E10.3,* YTEMP(J-1),*
     2  *YKMJM=*2E10.3)
      NSCRIB = 1
      GO TO 920
 410  CONTINUE
      DW=Z(LM)/AW
      IF (IJBUND .GT. 0) DW=2.*Z(LM)/(A234*(YKMJM+YTEMP(J-1)+YTEMP(J)))
      DTA=DT/(AW+A(LM))
      YH23=(YTEMP(J)+Y(LMJ))/2.-YHMM
      YH24=(YTEMP(J)+Y(LMJ)-YTEMP(J-1)-Y(LKM))/2.
      XH23=(XTEMP(J)+X(LMJ))/2.-XHMM
      XH24=(XTEMP(J)+X(LMJ)-XTEMP(J-1)-X(LKM))/2.
      XDH23=XDTEMP(J)-XD(LMM)
      XDH24=XDTEMP(J)-XDTEMP(J-1)
      YDH23=YDTEMP(J)-YD(LMM)
      YDH24=YDTEMP(J)-YDTEMP(J-1)
      DELX=AMIN1(DELX,A234**2/(AMAX1(XH23**2+YH23**2,XH24**2+YH24**2,
     1     (XHMM-X(LKM))**2+(YHMM-Y(LKM))**2)))
      EVOL=2.*(D(LM)-DW)/(D(LM)+DW)
      EXXH=DTA*(XDH23*YH24-XDH24*YH23)
      EYYH=DTA*(YDH24*XH23-YDH23*XH24)
      EXYH=DTA*(XDH24*XH23-XDH23*XH24+YDH23*YH24-YDH24*YH23)/2.
      EZZH=EVOL-EXXH-EYYH
      ALFA=DTA*(XDH23*XH24-XDH24*XH23+YDH23*YH24-YDH24*YH23)/2.
      GO TO 430
420   AW=0.5*(A124+A234)
      IF (AW.GT.O.) GO TO 425
      IF (AW .LE. O.) PRINT 95,K,J,A124,A234,XNW,XTEMP(J),XTEMP(J-1),
     1  XKMJM,YNW,YTEMP(J),YTEMP(J-1),YKMJM
 95   FORMAT(* K,J=*2I3,* A124,A234=*2E10.3,* XNW,XTEMP(J),XTEMP(J-1)=*
     1  3E10.3/* XKMJM,YNW,YTEMP(J)=*3E10.3,* YTEMP(J-1),YKMJM=*2E10.3)
      NSCRIB = 1
      GO TO 920
 425  CONTINUE
      DW=Z(LM)/AW
      IF (IJBUND .GT. 0) DW=2.*Z(LM)/(A124*(YTEMP(J-1)+YNW+YTEMP(J))+
     1  A234*(YKMJM+YTEMP(J-1)+YTEMP(J)))
C
C   ****   COMPUTE STRAINS
C
      DTA=DT   /(AW+A(LM))
      XH13=(X(LM)+XNW)/2.-XHMM
      XH42=(XTEMP(J-1)+X(LKM)-XTEMP(J)-X(LMJ))/2.
      YH13=(Y(LM)+YNW)/2.-YHMM
      YH42=(YTEMP(J-1)+Y(LKM)-YTEMP(J)-Y(LMJ))/2.
      XDH13=XDNH-XD(LMM)
      XDH42=XDTEMP(J-1)-XDTEMP(J)
      YDH13=YDNH-YD(LMM)
      YDH42=YDTEMP(J-1)-YDTEMP(J)
C     CALCULATE THE SHORTEST DISTANCE BETWEEN TWO SIDES OF
C     THE CALCULATIONAL CELL USING VECTOR DOT PRODUCTS
C
C     DEFINE COORDINATES OF CELL
C
      X1=0.5*(X(LM)+XNW)
      X2=0.5*(XTEMP(J)+X(LM))
      X3=XHMM
      X4=0.5*(XTEMP(J-1)+X(LKM))
      Y1=0.5*(Y(LM)+YNW)
      Y2=0.5*(YTEMP(J)+Y(LMJ))
      Y3=YHMM
      Y4=0.5*(YTEMP(J-1)+Y(LKM))
C
C     VECTOR V43 = (X4-X3)I + (Y4-Y3)J
```

```
C       V34 = -V43
C       V41 = (X4-X1)I + (Y4-Y1)J
C     V14 = -V41
C       V12 = (X1-X2)I + (Y1-Y2)J
C       V21 = -V12
C       V23 = (X2-X3)I + (Y2-Y3)J
C       V32 = -V23
C
C      CALCULATE THE MAGNITUDE SQUARED OF THE VECTORS
C
       XMAG43=(X4-X3)**2+(Y4-Y3)**2
       XMAG41=(X4-X1)**2+(Y4-Y1)**2
       XMAG12=(X1-X2)**2+(Y1-Y2)**2
       XMAG23=(X2-X3)**2+(Y2-Y3)**2
C
C       CALCULATE THE DOT PRODUCT
C
       D432=-((X4-X3)*(X3-X2)+(Y4-Y3)*(Y3-Y2))
       D321=-((X3-X2)*(X2-X1)+(Y3-Y2)*(Y2-Y1))
       D214=-((X2-X1)*(X1-X4)+(Y2-Y1)*(Y1-Y4))
       D143=-((X1-X4)*(X4-X3)+(Y1-Y4)*(Y4-Y3))
C
C      CHECK TO SEE IF PROJECTION LIES INSIDE CELL
C
       IF ( D432 .LE. 0.0 ) D432=0.0
       IF ( D321 .LE. 0.0 ) D321=0.0
       IF ( D214 .LE. 0.0 ) D214=0.0
       IF ( D143 .LE. 0.0 ) D143=0.0
       D432=D432**2
       D321=D321**2
       D214=D214**2
       D143=D143**2
C
C       NOW FIND MIN. DISTANCE
C
       DELX=AMIN1( XMAG43-D432/XMAG23 ,
     1             XMAG23-D432/XMAG43 ,
     2             XMAG23-D321/XMAG12 ,
     3             XMAG12-D321/XMAG23 ,
     4             XMAG12-D214/XMAG41 ,
     5             XMAG41-D214/XMAG12 ,
     6             XMAG41-D143/XMAG43 ,
     7             XMAG43-D143/XMAG41 )
       EVOL=2.*(D(LM)-DW)/(D(LM)+DW)
       EXXH=DTA*(XDH42*YH13-YH42*XDH13)
       EYYH=-DTA*(YDH42*XH13-XH42*YDH13)
       EXYH=0.5* DTA*(YDH42*YH13-YH42*YDH13-XDH42*XH13+XH42*XDH13)
       EZZH=EVOL-EXXH-EYYH
       ALFA=0.5*DTA*(-YDH42*YH13+YH42*YDH13-XDH42*XH13+XH42*XDH13)
430    MAT=MM(K,J)
C
C     COMPUTE ARTIFICIAL VISCOUS STRESS
C
       DELD = DW-D(LM)
       IF (ABS(DELD) .LT. 1.E-8 .AND. E(LM) .LT. 1.) GO TO 690
       IF (DELD .GT. 0.)
      1Q=DELD/DT*(SP(MAT)*CLIN*SQRT(AW)+CQSQ*AW*DELD/DW/DT)
C
C     COMPUTE ESTIMATE OF INTERNAL ENERGY
C
       DELZ=(SXX(LM)*EXXH+SYY(LM)*EYYH+SZZ(LM)*EZZH+2.*TXY(LM)*EXYH)/DW
       EW=E(LM)+DELZ-(P(LM)+Q)*(1./DW-1./D(LM))
C
C      STRESS FROM COMPOSITE MODEL
C
       IF (NCMP(MAT) .EQ. 0)  GO TO 450
       SXXW=SXX(LM)
       SYYW=SYY(LM)
       SZZW=SZZ(LM)
       TXYW=TXY(LM)
       PW=P(LM)
       CALL REBAR(0,5,J,K,MAT,N,IH(LM),DW,D(LM),SXXW,SYYW,SZZW,TXYW,EW,PW
     1 ,EXXH,EYYH,EZZH,EXYH,F,TH(LM),-ALFA, ESC,FS(LM),DSTL(LM),SRS(LM),
     2 ZEVP(LM),TEVP(LM),YY(LM),ROLD(LM),IPR)
       TH(LM)=TH(LM)-ALFA
```

```
      GO TO 600
C
C     STRESS FROM POROUS MODEL
C
450   IF (NPOR(MAT)  .EQ. 0)  GO TO 475
      IF (NPOR(MAT) .EQ. 4) GO TO 455
      CALL POREQST(1,5,MAT,SP(MAT),DW,D(LM),EW,E(LM),F,PW,CZJ,CWJ,IH(LM)
     1  ,DPDE,EQSTC(MAT),EQSTD(MAT),EQSTG(MAT),EQSTS(MAT),MU(MAT),
     2  RHOS(MAT),YAD(MAT),NDS(MAT),NPR(MAT),J)
      GO TO 550
455   CONTINUE
      SX=SXX(LM)-P(LM)
      SY=SYY(LM)-P(LM)
      SZ=SZZ(LM)-P(LM)
      TXYW=TXY(LM)
      CALL CAP1(1,5,MAT,N,IH(LM),DW,D(LM),EW,EXXH,EYYH,EZZH,EXYH,
     1  SX,SY,SZ,TXYW,ZEVP(LM),K,J,TEVP(LM))
      PW=-(SX+SY+SZ)/3.
      SXXW=SX+PW
      SYYW=SY+PW
      SZZW=SZ+PW
      GO TO 600
C
C     STRESS FROM FRACTURE MODEL
C
475   IF (NFR(MAT) .EQ. 0) GO TO 500
      NFRM=NFR(MAT)
      GO TO (477,485,490,490,500,500,495)NFRM
C
C     DUCTILE FRACTURE
C
477   IF (P(LM)  .GT. TSR(MAT,5) .AND.  IH(LM)  .EQ. 2)  GO TO 500
      SXXW=+SXX(LM)
      SYYW=+SYY(LM)
      SZZW=+SZZ(LM)
      TXYW=+TXY(LM)
      PW=P(LM)
      CALL DFRACT(SXXW,SYYW,SZZW,TXYW,+EXXH,+EYYH,+EZZH,+EXYH,PW,
     1  ENM(LM),ENT(LM),DW,D(LM),DT   ,E(LM),EW,EQSTC(MAT),EQSTG(MAT),
     2  MU(MAT),RHOS(MAT),TSR,YY(LM),YD(MAT),F,MAT,ALFA)
      IH(LM)=3
      GO TO 600
C
C     BRITTLE FRACTURE
C
485   IF (AMAX1(TXX(LM),TYY(LM),TZZ(LM)) +Q .LT.-TSR(MAT,5)
     1  .AND.  IH(LM) .EQ.2)  GO TO 500
      IH(LM)=1
      SXXW=SXX(LM)
      SYYW=SYY(LM)
      SZZW=SZZ(LM)
      TXYW=TXY(LM)
      TXYW=-TXY(LM)
      PW=P(LM)
      LS=LSFRACT
      IF (MOD(N,IPRINT) .EQ. 0 .AND. LS .NE. 0) LS=2
      CALL FRAG(LS,5,MAT,J,K,N,IH(LM),EQSTC(MAT),DW,D(LM),DT,EW,E(LM),
     1   EXXH,EYYH,EXYH,F,FF(LM),MU(MAT),EQSTG(MAT),RHOS(MAT),TH(LM),
     2   -ALFA,PW,SXXW,SYYW,TXYW,YY(LM),TSR,CLB(LM),CL1(LM),CN(LM),
     3   COM(LM+37))
      LSFRACT=1
      TH(LM)=TH(LM)-ALFA
      SZZW=-SXXW-SYYW
      GO TO 600
C
C        SHEAR BAND MODEL
C
490   SXXW=SXX(LM)
      SYYW=SYY(LM)
      SZZW=SZZ(LM)
      TXYW=TXY(LM)
      PW=P(LM)
      EMELT=0.1*EQSTE(MAT)
      LS = 2
      IF (MOD(N,IPRINT) .EQ. 0) LS = 3
```

```
      CALL SHEAR2(LS,5,MAT,K,J,IH(LM),SXXW,SYYW,TXYW,PW,COM(L+24),DW,
     1 D(LM),DT,EW,E(LM),COM(LM+21),EMELT,COM(LM+22),EXXH,EYYH,EXYH,
     2 F,YY(LM),COM(LM+23),TH(LM),-ALFA,ESC,COM(LM+25))
      SZZW=-SXXW-SYYW
      TH(LM)=TH(LM)-ALFA
      GO TO 600
C     STATIC FRACTURE MODEL
C
 495  LS=LSFRACT
      IF (IHEAD .GT. 1 .AND. LS .NE. 0) LS=2
      SXXW=SXX(LM)
      SYYW=SYY(LM)
      SZZW=SZZ(LM)
      TXYW=TXY(LM)
      PW=P(LM)
      CALL DFRACTS(LS,J,K,N,IH(LM),MAT,SXXW,SYYW,SZZW,TXYW,PW,EXXH,EYYH,
     1  EZZH,EXYH,DW,D(LM),YY(LM),EW,E(LM),COM(LM+19),TSR,ESC)
      LSFRACT=1
      GO TO 600
C
C     MODELS FOR PRESSURE
C
500   CONTINUE
      NPRM=NPR(MAT)+1
      GO TO (520,510) NPRM
C
C     PRESSURE FROM EXPLOSION
C
510   CONTINUE
      CALL EXPLODE(3,5,MAT,EW,DW,D(LM),PW,Q,COM(18+LM),COM(19+LM),
     1  COM(20+LM),YNW,YNW-Y(LKM),J,K,TYME)
      GO TO 550
520   CONTINUE
C
C     PRESSURE FROM MIE-GRUNEISEN
C
      EMU=DW/RHO(MAT)-1.
      PHUG=+EMU*(EQSTC(MAT)+EMU*(EQSTD(MAT)+EMU*EQSTS(MAT)))
      PW=PHUG*(1.-EQSTG(MAT)*EMU/2.)+EQSTG(MAT)*DW*EW
C
C     MODELS FOR DEVIATOR STRESS
C
550   CONTINUE
      IF (NDS(MAT) .EQ. 7) GO TO 560
      IF (YC(MAT) .LE. 0.) GO TO 600
      EAVG=EVOL/3.
      BETA=2.*TXY(LM)*ALFA
      SXXW=SXX(LM)+G2(MAT)*(EXXH-EAVG)+BETA
      SYYW=SYY(LM)+G2(MAT)*(EYYH-EAVG)-BETA
      SZZW=SZZ(LM)+G2(MAT)*(EZZH-EAVG)
      TXYW=TXY(LM)+G2(MAT)*EXYH+(SYY(LM)-SXX(LM))*ALFA
      SJ2=SXXW**2+SYYW**2+SZZW**2+2.*TXYW**2
      YYY=0.666667*YY(LM)**2
      IF (SJ2 .LE. YYY)  GO TO 600
      CY=SQRT(YYY/SJ2)
      SXXW=CY*SXXW
      SYYW=CY*SYYW
      SZZW=CY*SZZW
      TXYW=CY*TXYW
      GO TO 600
560   SXXW=SXX(LM)
      SYYW=SYY(LM)
      SZZW=SZZ(LM)
      TXYW=TXY(LM)
      CALL EP(1,MAT,N,SXXW,SYYW,SZZW,TXYW,YY(LM),EXXH,EYYH,EZZH,EXYH,
     1 MU(MAT),COM(LM+19))
C
C     ADJUST INTERNAL ENERGY
C
600   IF (NPR(MAT) .EQ. 1) GO TO 620
      EW=E(LM)+0.5*((SXX(LM)+SXXW)*EXXH+(SYY(LM)+SYYW)*EYYH+(SZZ(LM)+
     1 SZZW)*EZZH+2.*(TXY(LM)+TXYW)*EXYH)/DW-((P(LM)+PW)/2.+Q)*(1./DW-
     2 1./D(LM))
C
C     COMPUTE TOTAL STRESS
```

```
C
620   TXXW=SXXW-PW-Q
      TYYW=SYYW-PW-Q
      TZZW=SZZW-PW-Q
C
C     SEPARATION FOR GUARD RING OR IMPACT PLANE
C
      IF (NFR(MAT) .NE. 5 .AND. NFR(MAT) .NE. 6) GO TO 690
      IF (NFR(MAT) .EQ. 6 ) GO TO 650
      IF (TXXW .LE. TSR(MAT,1)) GO TO 690
      P1=TXXW*EQSTC(MAT)/(EQSTC(MAT)+1.333*MU(MAT))
      DSX=1.333*TXXW*MU(MAT)/(EQSTC(MAT)+1.333*MU(MAT))
      TXXW=TXXW-DSX-P1
      TYYW=TYYW-P1+DSX/2.
      TZZW=TZZW-P1+DSX/2.
      PW=-(TXXW+TYYW+TZZW)/3.
      TXYW=0.
      GO TO 680
650   IF (TYYW .LE. TSR(MAT,1)) GO TO 690
      P1=TYYW*EQSTC(MAT)/(EQSTC(MAT)+1.333*MU(MAT))
      DSY=1.333*TYYW*MU(MAT)/(EQSTC(MAT)+1.333*MU(MAT))
      TXXW=TXXW-P1+DSY/2.
      TYYW=TYYW-P1-DSY
      TZZW=TZZW-P1+DSY/2.
      PW=-(TXXW+TYYW+TZZW)/3.
      TXYW=0.
680   IF (IH(LM) .EQ. 1) GO TO 690
      IH(LM)=1
      PRINT 1680,K,J
1680  FORMAT(* SEPARATION AT CELL K,J =*2I4)
C
C    COMPUTE SOUND SPEED  AND TIME STEP
C
690   EMOD=0.
      SPSQ=SP(MAT)**2
      IF (ABS(DW-D(LM)) .LT. 1.E-4) GO TO 700
      EMOD=PW/(DW/RHO(MAT)-1.)+2.*Q*DW/(DW-D(LM))+1.33*MU(MAT)
      SPSQ=AMAX1(EMOD/D(LM),0.2*SPSQ)
700   DTSQ=DELX/SPSQ
      IF (DTSQ .GE. DTSQM)  GO TO 750
      KT=K
      JT=J
      DELXT=DELX
      DTSQT=DTSQ
      SPSQT=SPSQ
      DTSQM=DTSQ
C
C   ******  MAJOR PRINTOUT
C
750   GO TO (780,755,760)  IHEAD
755   PRINT 1755,N,TYME,DT,CALTIM,KT,JT,DELXT,DTSQT,SPSQT,LISTX,
     1  LISTXD,LISTS,LISTE
      IHEAD=3
      GO TO 761
 760  GO TO(765,761,780) KHEAD
761   IF (MOD(N,KFULL) .EQ. 0) GO TO 763
      KHEAD=3
      IF (K .GT. KPMAX .OR. K .LT. KPMIN) GO TO 780
      IF (MOD(K-KPMIN,KSKIP) .NE. 0) GO TO 780
763   ZX=XNW*CALX
      ZY=YNW*CALX
      ZXD=XDNH*CALXD
      ZYD=YDNH*CALXD
      PRINT 1756,K,N,TYME,ZX,ZY,ZXD,ZYD
      KHEAD=1
      GO TO 780
 765  IF(I .GT. JPMAX .OR. J .LT. JPMIN) GO TO 780
      ZX=XNW*CALX
      ZY=YNW*CALX
      ZXX=TXXW*CALS
      ZYY=TYYW*CALS
      ZZZ=TZZW*CALS
      ZXY=TXYW*CALS
      ZE=EW*CALE
      ZP=PW*CALS
      ZQ=Q*CALS
```

```
      ZSP=SPSQ*1.E-10
      ZXD=XDNH*CALXD
      ZYD=YDNH*CALXD
      ICOND=0
      IF (MM(K,J) .GT. 0 .AND. NVAR(MAT) .GE. 2) ICOND=IH(LM)
      PRINT 1760,J,ZX,ZY,ZXX,ZYY,ZZZ,ZXY,ZP,ZE,DW,ZQ,ZSP,ZXD,ZYD,ICOND
     1   ,AMAT(MAT,1)
  780 CONTINUE
      IF (ITRI .EQ. 1) GO TO 795
      IF (K .EQ. 1) GO TO 790
      IF (J .EQ. 1) GO TO 785
      LMM=LVAR(K-1,J-1)
      IF (LMM .LE. 0) GO TO 785
      X(LMM)=XKMJM
      Y(LMM)=YKMJM
  785 CONTINUE
      LMJ=LVAR(K-1,J)
      IF (LMJ .LE. 0) GO TO 790
      XHMM=(X(LMJ)+XTEMP(J))/2.
      YHMM=(Y(LMJ)+YTEMP(J))/2.
      XKMJM=XTEMP(J)
      YKMJM=YTEMP(J)
      XD(LMJ)=XDTEMP(J)
      YD(LMJ)=YDTEMP(J)
  790 IF (LVARM .LE. 0) GO TO 920
      XTEMP(J)=XNW
      YTEMP(J)=YNW
      XDTEMP(J)=XDNH
      YDTEMP(J)=YDNH
      IF (MM(K,J) .EQ. 0) GO TO 800
  795 LM=LVARM
      IF (ITRI .EQ. 2) LM=M(LM)
      D(LM)=DW
      E(LM)=EW
      SXX(LM)=SXXW
      SYY(LM)=SYYW
      SZZ(LM)=SZZW
      TXY(LM)=TXYW
      TXX(LM)=TXXW
      TYY(LM)=TYYW
      TZZ(LM)=TZZW
      P(LM)=PW
      IF (ITRI .EQ. 1) GO TO 405
  800 IF (K .NE. JEDK(JE) .OR. J .NE. JEDJ(JE)) GO TO 920
      IF (JEDT(JE) .LT. 0) GO TO 820
      LM=LVAR(K,J)
      LL=LM+JEDT(JE)-1
      SJ(JE)=X(LL)
      IF (JEDT(JE) .EQ. 18) SJ(JE)=IH(LM)
  810 JE=JE+1
      GO TO 800
  820 JJ=IABS(JEDT(JE))-40
      GO TO (841,842,843,844,845,846,847,848,849,850,851,852,853,
     1   854,855)JJ
  841 CONTINUE
  842 CONTINUE
  843 CONTINUE
  844 CONTINUE
  845 SJ(JE)=0.47140*SQRT((EXXH-EYYH)**2+(EYYH-EZZH)**2+(EZZH-EXXH)**2
     1   +6.*EXYH**2)+SJ(JE)
      GO TO 810
  846 SJ(JE)=EXXH+SJ(JE)
      GO TO 810
  847 SJ(JE)=EYYH+SJ(JE)
      GO TO 810
  848 SJ(JE)=EZZH+SJ(JE)
      GO TO 810
  849 SJ(JE)=EXYH+SJ(JE)
      GO TO 810
  850 SJ(JE)=Q
      GO TO 810
  851 SJ(JE)=SXXW-PW
      GO TO 810
  852 SJ(JE)=SYYW-PW
      GO TO 810
```

SUBROUTINE SWEEPT (Concluded)

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853   SJ(JE)=SZZW-PW
      GO TO 810
 854  EF=0.
      NP=1
      IF (IJBUND .GT. 0)NP=2
      KK=MAX0(K-1,1)
      LM1=LVAR(KK,1)
      DO 8545 JST=2,JMAX
      LM2=LVAR(KK,JST)
      LMS=LVAR(K,JST)
      EF=EF+TXX(LMS)*(Y(LM2)**NP-Y(LM1)**NP)
 8545 LM1=LM2
      SJ(JE)=EF/Y(LM2)**NP
      GO TO 810
 855  LM1=LVAR(K,JMAX)
      IF(N .EQ. 1) RADO=Y(LM1)
      SJ(JE)=-2.*ALOG(Y(LM1)/RADO)
      GO TO 810
920   CONTINUE
      IF (K .EQ. 1) GO TO 940
      LMJ=LVAR(K-1,JMAX)
      IF (LMJ .LE. 0) GO TO 940
      X(LMJ)=XKMJM
      Y(LMJ)=YKMJM
940   KK=K
      IF (K .LT. KCHEK .OR. K .EQ. KMAX) GO TO 950
      DO 945 J=1,JMAX
      LMJ=LVAR(K,J)
      IF (LMJ .LE. 0) GO TO 945
      IF (ABS(XD(LMJ)).GT. 1. .OR. ABS(YD(LMJ)).GT. 1.) GO TO 948
945   CONTINUE
      GO TO 960
948   KCHEK=MINO(K+1,KMAX)
      GO TO 960
950   CONTINUE
960   CONTINUE
      DO 980 J=1,JMAX
      LMJ=LVAR(KK,J)
      IF(LMJ .LE. 0)GO TO 980
      X(LMJ)=XTEMP(J)
      Y(LMJ)=YTEMP(J)
      XD(LMJ)=XDTEMP(J)
      YD(LMJ)=YDTEMP(J)
 980  CONTINUE
      DTW=SQRT(DTSQM)*(1.-3.*TRIQ)
      RETURN
C ******        FORMATS
C
1755  FORMAT (15HO EDIT AT CYCLEI4,7H, TYME=E10.4,12H SECS,  DT =E10.4,
     1  9H, CALTIM=1PE10.3/31H   TIME STEP CONTROL AT KT, JT=2I4,
     2  18H DELX, DTSQ, SPSQ=1P3E13.5/ 11H   X, Y IN ,A3,12H, XD, YD IN
     3  A6,14H, STRESSES IN A7,7H, E IN A7,29H, D IN MG/M3, SP IN (KM/SE
     4C)2 )
1756  FORMAT(10H COLUMN K=I3,4H, N=I4,7H, TIME=  E10.4,4H, X=F8.4,4H, Y=
     1  F8.4,38X,11HXDNH, YDNH=2F9.3/ 3H  J7X,1HX7X,1HY7X,4HTXXW7X,
     2  4HTYYW7X,4HTZZW7X,4HTXYW10X,1HP6X,1HE9X,1HD10X,1HQ5X,4HSPSQ5X,
     3  4HXDNH5X,4HYDNH2X,1HH)
1760  FORMAT (I3,2F8.4,5F11.4,F7.1,F10.6,F11.4,3F9.3,I3,A4)
      END
```

Appendix F

GLOSSARY

The nomenclature for this manual is given in two groups. First, symbols used in the derivations are listed, followed by the input quantities and other major variables in the computer program.

Nomenclature of Text

A	Cell area, cm^2
A_{xx}	Area of cell facing the x direction, cm^2
A_{xy}	Area of cell in the xy plane, cm^2
A_{yy}	Area of cell facing the y direction, cm^2
A_0, A_3	Area of two triangular portions of a quadrilaterial cell, cm^2
b	Number of cells over which a detonation front is spread.
C, D, S	Coefficients in the series expansion for Hugoniot pressure, dyn/cm^2
C'	Effective sound speed considering only bulk and shear moduli, cm/sec
C_e	Effective sound speed for determining the time step, cm/sec
C_s	Sound speed, cm/sec
C_o	Coefficient of quadratic artificial viscosity relation
C_1	Coefficient of linear artificial viscosity relation
D_x	Detonation velocity, cm/sec
E	Internal energy, erg/g
E_{CJ}	Internal energy at the C-J point, erg/g
E_H	Internal energy on the Hugoniot, erg/g
F_B	Detonated fraction of an explosive
F_x	Force in the x direction, dyn
F_y	Force in the y direction, dyn
G	Shear modulus, dyn/cm^2
J	Lagrangian position (radial for axisymmetric geometry)
K	Lagrangian position (axial for axisymmetric geometry)

M	Material number; or cell mass
M_e	Effective modulus for determining the time step, dyn/cm^2
n	Time step number
P	Pressure, dyn/cm^2
P_{CJ}	Pressure at the C-J point, dyn/cm^2
P_H	Hugoniot pressure, dyn/cm^2
Q	Artificial viscous stress, dyn/cm^2
Q_x	Chemical energy of the explosive, erg/g
Q_{xx}, Q_{yy}, Q_{xy}	Triangular artificial viscosity stresses, dyn/cm^2
T	Total mechanical stress, dyn/cm^2
T_q	Coefficient of triangular artificial viscosity relation
T_{xx}	Total stress in the x direction, dyn/cm^2
T_{xy}	Shear stress on the xy plane, dyn/cm^2
T_{yy}	Total stress in the y direction, dyn/cm^2
T_{zz}	Total stress in the z direction, dyn/cm^2
t	Time in the problem, sec
Δt	Time increment, sec
u	Particle velocity in the x direction, cm/sec
u_{CJ}	Particle velocity at the C-J point, cm/sec
u_0, u_x, u_y	Constants in the series expansion for particle velocity in the x direction
V	Specific volume, cm^3/g
V_{CJ}	Specific volume at the C-J point, cm^3/g
v	Particle velocity in the y direction, cm/sec
v_o, v_x, v_y,	Constants in the series expansion for particle velocity in the y direction

x	Coordinate location in x direction, cm (axial for axisymmetric geometry)
$\dot{x}$	Particle velocity in the x direction, cm/sec
X_D, Y_D	Coordinates of the initiation point of an explosive, cm
y	Coordinate location in y direction, cm, (radial for axisymmetric geometry); or yield strength, dyn/cm^2
$\dot{y}$	Particle velocity in the y direction, cm/sec
Z	Quantity stored as the cell mass: for planar cells, Z is the mass in g/cm; for axisymmetric cells, Z is the 1.5/π times the mass in g.
$\overline{Z}$	Cell midpoint used in explosive calculations, cm
Z_D	Initiation point for a detonation, cm
Γ	Grüneisen ratio
γ	Polytropic gas exponent
γ_{xy}	Engineering shear strain
δ_{ij}	Kronecker delta: $\delta = 1$ for $i = j$; otherwise, $\delta = 0$
ε_{ij}	Tensor strain component
ε'_{ij}	Deviator strain
ε'^{E}_{ij}	Elastic deviator strain
$\overline{\varepsilon}^{p}$	$\sqrt{\frac{2}{3}\varepsilon^{p}_{ij}\varepsilon^{p}_{ij}}$, equivalent plastic strain
ε^{p}_{ij}	Plastic strain tensor
ε_x	Strain in the x direction
ε_y	Strain in the y direction
ε_z	Strain in the z direction
θ	Angle in a circumferential direction

λ	Proportionality factor used in plastic flow stress-strain relation, cm^2/dyn
μ	$\rho/\rho_o - 1$, strain
ρ	Cell density, g/cm^3
ρ_o	Initial density, g/cm^3
σ	Stress, dyn/cm^2
σ_{ij}	Tensor stress component, dyn/cm^2
σ'_{ij}	Deviator stress, dyn/cm^2
$\bar{\sigma}$	$\sqrt{\frac{3}{2}\sigma'_{ij}\sigma'_{ij}}$, effective stress, dyn/cm^2
σ'^{N}_{ij}	Stress component computed on an elastic basis, dyn/cm^2
$\bar{\sigma}^N$	$\sqrt{\frac{3}{2}\sigma'^{N}_{ij}\sigma'^{N}_{ij}}$, effective stress computed on an elastic basis, dyn/cm^2
ω_{xy}	Rotation in the xy plane, positive counterclockwise

Nomenclature of TROTT

A( )	Area of cell in the xy plane, cm^2
ALFA	Incremental cell rotation, positive clockwise
ANGLE	Angle of boundary for an oblique impact, deg
BFR( )	Material properties array used for fracture models
CALE, CALS, CALX, CALXD	Calibration factors for transforming energy, stress, distance and velocity respectively from the internal c.g.s. system to form the IPRINT listings in the units described by the names LISTE, LISTS, LISTX AND LISTXD.
CALTIM	Computation time from start of reading input, sec
CLIN	C_1; coefficient of linear artificial viscosity
COM( )	One-dimensional array containing all cell and coordinate variables
CQSQ	C_o^2; coefficient of quadratic artificial viscosity
D( )	Cell density, g/cm^3
DELTIM	Computation time for a time increment, sec
DT	Time increment, sec
DTN	One-half the current and previous time increments, sec
E( )	Internal energy, erg/g
EQSTC( ), EQSTD( ), EQSTS( )	C, D, S; coefficients in series expansion for Hugoniot pressure dyn/cm^2
EQSTE ( )	Sublimation energy, erg/g (unused)
EQSTG( )	Γ; Grüneisen's ratio
EQSTH( )	Gas Grüneisen's ratio (unused)
ESC( )	Large array for equation-of-state constants. See Appendix A for definitions

G2( )	2G; twice the shear modulus, dyn/cm^2
IBDJ1( ), IBDJ2( )	Range of J values designating a special boundary condition
IBDK1( ), IBDK2( )	Range of K values designating a special boundary condition
IBDX( ), IBDY( )	Indicators for displacement boundary condition control on the X or Y locations. The values mean: 0 Free, no control 1 No velocity change 2 X (or Y) is kept $\leq$ XFIX (or YFIX) 3 X (or Y) is kept $\geq$ XFIX (or YFIX)
ICAL	Indicator for special controls on the units used for IPRINT listings
IH( )	Indicator array used with some material models
IJBUND	Geometry and boundary indicator, see Table 1 in Section 5
IMAX	Maximum number of cycles for a run, or for the increment in a restarted run
IPRIND	An indicator for reading print options KSKIP, KFULL, KPMAX, KPMIN, JPMAX, and JPMIN to alter the normal edit listings
IPRINT	Frequency in computational cycles at which edit listings of cell and coordinate variables are requested
IVTYPE	Velocity initialization indicator, see Table 1 in Section 5
J	Lagrangian coordinate
JEDJ( ), JEDK( ), JEDT( )	J, K, and variable type values in a historical listing request. See Table 2 in Section 5
JMAX	Maximum J value in the layout

JPMAX, JPMIN	Maximum and minimum J values for which edit listings are given when the cycle is not a multiple of KFULL
JPRINT	Print indicator for obtaining edit listings at every cycle from JP1 to JP2. JPRINT is the number of groups of JP1 and JP2
JP1( ), JP2( )	Minimum and maximum computational cycles for which edit listings are requested at each cycle
JSIZE	Dimension of the COM array, set in TROTT (Section 5.5)
JSLIDE	Indicator for a slide line between J rows JSLIDE-1 and JSLIDE with master cells on the JSLIDE side
JU	Maximum J value initialized at the velocity UZERO
JXX	Maximum number of J values permitted, set in TROTT
J1, J2	Range of J values for a quadrilateral set of cells
K	Lagrangian coordinate
KCHEK	Maximum value of K treated in the wave propagation calculations
KFULL	Frequency in computational cycles at which a full edit listing is given
KMAX	Maximum K value in the layout
KPMAX, KPMIN	Maximum and minimum K values for which edit listings are given when the cycle is not a multiple of KFULL
KSKIP	Frequency in K values at which K columns are printed in an edit listing
KSLIDE	Indicator for a slide line between K rows KSLIDE-1 and KSLIDE with master cells on the KSLIDE-1 side
KU	Interface K value for a projectile impact. If IVTYPE = 1, rows 1 to KU are given an initial velocity. For IVTYPE = -1, rows KU to KMAX are given an initial velocity

KXX	Maximum number of K values permitted, set in TROTT
K1, K2	Range of K values for a quadrilateral set of cells
LISTE, LISTS, LISTX, LISTXD	Alphanumeric names for the units used in IPRINT listings for energy, stress, distance, and velocity, respectively
LVAR( )	Two-dimensional array containing locations in COM to begin data for each cell and coordinate
M, MAT, MM	Material number
MU( )	Shear modulus, dyn/cm^2
NBLOCK	Number of quadrilateral blocks used in providing the x,y geometric data
NBND	Number of special boundary groups, used only for IJBUND = ±9. See Appendix G
NCMP( )	Composite material indicator; nonzero means that the REBAR subroutine is used
NDS( )	Deviator stress model indicator (not used)
NDUMP	Frequency in computational cycles at which a restart dump is written to Tape 9
NEXED	Frequency in computational cycles at which listings are requested of all values in the COM array not in a normal edit
NEXTRA	Indicator for reading extra data through the EXTRAT subroutine
NFR( )	Fracture model indicator as follows: 0 no fracture model 1 ductile fracture, DFRACT 2 brittle fracture, BFRACT(3) 3 SHEAR2 shear band model

4 SHEAR2 shear band model

5 simple tensile fracture in the X direction

6 simple tensile fracture in the Y direction

7 static ductile fracture, DFRACTS

NJED	Number of historical listings requested
NMTRLS	Number of materials
NOBLQ	Indicator for an impact on a fixed oblique wall to be impacted by the material laid out
NPLOT	Frequency in computational cycles at which data for XY plots are written to Tape 3
NPOR( )	Porous material model indicator; nonzero means that CAP1 is used
NPR( )	Pressure model indicator; zero means Mie-Grüneisen and 1 is for explosives
NSTART	Number of the restart file to be used for a restart problem, zero for an original run (read from Tape 1)
NTRI( )	Indicator for separating each quadrilateral cell of the material into two triangular cells
NVAR( )	Number of additional variables (beyond the usual 17) to be assigned to each cell of the material
NVBLK	Number of quadrilateral blocks used in initializing the velocities
NYAM	Indicator for yielding; nonzero values permit initialization of yield strength and shear modulus
P( )	Pressure, dyn/cm^2
Q	Artificial viscous stress, dyn/cm^2
RHO( )	ρ; initial density, g/cm^3
RHOS( )	ρ_o; initial solid density, g/cm^3
SP( )	Sound speed, cm/sec

SXX( )	Deviator stress in the x direction, dyn/cm^2
SYY( )	Deviator stress in the y direction, dyn/cm^2
SZZ( )	Deviator stress in the z direction, dyn/cm^2
TANTH	Tangent of angle of fixed oblique wall
TH( )	Cell rotation, positive counterclockwise
TRIQ	T_q; coefficient of triangular artificial viscosity
TS	Input stop time, sec
TSR( )	Material properties array available for special models
TXX( )	Total stress in the x direction, dyn/cm^2
TXY( )	Shear stress on the xy plane, dyn/cm^2
TYME	Problem time, sec
TYY( )	Total stress in the y direction, dyn/cm^2
TZZ( )	Total stress in the z direction, dyn/cm^2
UZERO	U_z; initial velocity of an impactor, cm/sec
X( )	Eulerian position in the x direction, cm
XA, YA	Eulerian coordinate positions or velocities for a quadrilateral set of cells, read in counterclockwise order starting with point of smallest K, J values
XFIX( )	X value used with special boundary conditions, cm
XD( )	Particle velocity in the x direction, cm/sec
Y( )	Eulerian position in the y direction, cm
YAD( )	Work-hardening modulus, dyn/cm^2
YC( )	Y; initial yield strength, dyn/cm^2
YD( )	Particle velocity in the y direction cm/sec
YFIX( )	Y value used with special boundary conditions, cm
YY( )	Yield strength for a cell, dyn/cm^2
Z( )	Mass of a cell, g/cm or g

Appendix G

SPECIAL BOUNDARY CONDITIONS

In addition to the standard boundary conditions specified by IJBUND = ±1 to ±5, special kinematic conditions can be applied at individual points or along K or J lines. These conditions can be adjusted to fix a point in the X or Y directions, to maintain its X or Y velocity, or to keep the point within specified bounds.

The special boundary conditions are provided for IJBUND = ±9 (negative for planar and positive for axisymmetric). The input parameter NBND then gives the number of special boundary conditions to be provided. For each boundary condition, values of IBDJ1, IBDJ2, IBDK1, and IBDK2 give the range of J and K values affected. Note that a range in only one (J or K) is permissible; otherwise, the boundary condition would affect interior points. Along the boundary IBDY and IBDX specify how the X and Y directions are to be treated:

IBDX or IBDY	=	0	No control, free boundary
		1	No change in velocity permitted
		2	X (or Y) is required to be $\leq$ XFIX (or YFIX)
		3	X (or Y) is required to be $\geq$ XFIX (or YFIX)

The other two quantities XFIX and YFIX provide maximum or minimum values of the X and Y locations. For example, the radii along the axis of symmetry can be kept on the axis by specifying IBDY = 1 (Y is radial).

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